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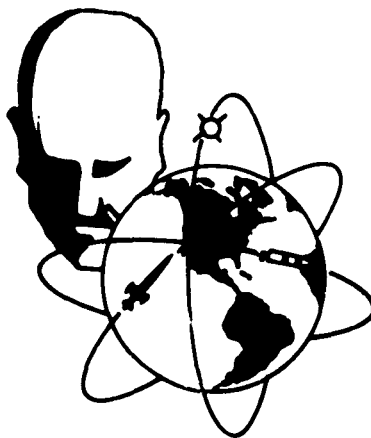
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RADAR INTERFERENCE STUDY
INTERIM REPORT

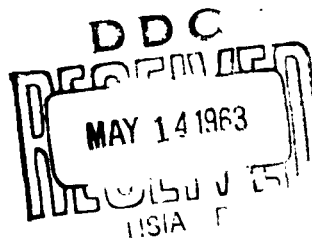
TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-63-221
JANUARY 1963

Walter B. Mills

482L SYSTEMS PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



(Prepared under Contract AF 19(604)-8484 by Sylvania Electronics Systems-East
Sylvania Electronics Systems, Division of Sylvania Electric Incorporated)



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ABSTRACT

This report covers a study of the electrical characteristics common to "angel" signal phenomenon encountered at L band radar sites. Photographic and magnetic tape storage techniques have been used to record doppler frequency, doppler bandwidth, and pulse width information associated with these "unknown signals". Data reduction results for a number of "angel" signal samples have been tabulated and discussed in this report. Two possible circuit cures to eliminate the angel interference from the MTI portion of radar systems are described.

LIST OF CONTENTS

<u>Section</u>	<u>Page</u>
ABSTRACT	ii
LIST OF ILLUSTRATIONS	iv
I INTRODUCTION	1
II DATA GATHERING TECHNIQUES AT THE FORT DAWES SITE	2
High Speed Film Technique	2
Boxcar Recording and Playback Technique	5
PPI Photographic Technique	7
III CONDITION OF FPS-8 RADAR DURING DATA GATHERING PERIOD	11
Receiver Sensitivity	11
Cancellation Ratio (MTI System)	11
Coherence of MTI System	11
Duplexer Recovery Time	11
IV DATA GATHERED AND RESULTS	13
Single Type Angel Return	13
Group Angel Return	17
Miscellaneous Unknown Return	17
Weather Return	24
Aircraft Signal Samples	24
V SUMMARY	33
VI CONCLUSIONS	34
VII APPENDIX	37
Previous Studies on Angel Activity	37
Airborne Instruments Laboratory Study	37
Lincoln Laboratory Study	38
Geophysics Research Directorate Study	39
VIII BIBLIOGRAPHY ON RADAR ANGEL RETURN	40

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
A	Diagram of Range Mark Generation for Scope Used in High Speed Photography	3
B	Range Mark Combiner Circuit	4
C	Balanced DC Recorder Input - Circuit	8
D	Boxcar Record and Playback System	6
E	PPI and High Speed Camera Installations	9
F	"Boxcar" Recording and Playback Equipment	10
1	Single Type Angel Displays	14
2	"Boxcar" Data of Single Type Angel Return	15
3	"Boxcar" Data of Single Type Angel Return	16
4	Group Angel Displays	18
5	"Boxcar" Data of Group Angel Return	19
6	"Boxcar" Data of Group Angel Return	20
7	"Boxcar" Data of Group Angel Return	21
8	High Speed 35 mm Bi-Polar Cancelled Video Return	22
9	Miscellaneous Unknown Displays	23
10	Weather Displays	25
11	"Boxcar" Data of Weather Return	26
12	"Boxcar" Data of Weather Return	27
13	"Boxcar" Data of An Aircraft Return	28
14	"Boxcar" Data of An Aircraft Return	29
15.	"Boxcar" Data of An Aircraft Return	30
16	Adjustable Offset Coho	35
17	Modified Non-Coherent MTI	36

I. INTRODUCTION

The Radar Interference Study described in this report was undertaken by Sylvania Waltham Laboratory personnel starting in May 1961 at the Air Force ESD installation Fort Dawes, Deer Island. Main goals of the study was to attempt to learn as much as possible about "angel" type interference phenomenon which still represents a serious problem to air traffic control radars throughout the world. An L Band FPS-8 radar system located at the Fort Dawes site was utilized during the active surveillance period from May 1961 to November 1962. Over this time period, information was recorded by film and magnetic tape storage techniques. A total of 26 "angel" samples termed "single type angel" were recorded as well as 4 angel samples termed "group angel type". Also various miscellaneous "angel" samples together with weather and aircraft samples were recorded. In addition to observing and recording "angel" data, a considerable amount of time was devoted to data reduction, instrumentation techniques and equipment modification, and to an improvement in radar performance through a period of "peaking up" the circuitry.

This report commences with a discussion of the measurement techniques employed during the study, and continues into a detailed description of the "angel" types encountered at the Fort Dawes Site.

II. DATA GATHERING TECHNIQUES AT THE FORT DAWES SITE

High Speed Film Technique

Due to the importance of studying bi-polar video on a short term basis with regards to "angel" return a method of high speed 35 mm photography was devised for the Sylvania study. Short term recordings were felt to be necessary since previous studies reported a variety of "angel" return time durations. Since a short persistence time was desirable for the "A" scope high speed photography (in order to prevent multiple exposures) a Tektronix Type 514D oscilloscope using a short persistence CRT was found suitable. Cancelled video information from the MTI system was fed to the vertical input. Cancelled video was chosen over coherent video because it would eliminate fixed targets thus making eventual film analysis more meaningful. Application of the system trigger provided scope synchronization. A dumont Type 321A oscillograph record camera with a lens exposure setting of ± 5.6 and a film speed of 5400 inches/minute photographed each radar pulse period with good separation between successive sweeps. Range marks from two UPA-35 PPI indicators were applied to the cathode circuit of the oscilloscope CRT following combining and amplification through use of a range mark combiner circuit.

The range mark combiner circuit shown in Figure B was required because the UPA-35 generates range marks every other trace and range marks were required on every trace to properly blank the "A" scope. Since the PPI range mark generators start in random fashion it was necessary to remove the input trigger to one of the UPA-35 indicators as shown in the block diagram of Figure A, to get indicator range marks firing on alternate triggers. Range marks matching the 2, 5, 10, or 20 mile marks of the UPA-35 were thus made available to 12AU7 and the "A" scope used for the high speed photography.

The operating sequence using the above set-up was to search-light on a particular target or group of targets and then run one to two seconds of high speed film to record the trace by trace information displayed on the 514D. Typical examples of the type of pictures obtained are given later in the report where the various types of "unknown" targets are discussed. A vertical signal deflection of 1-2 cm was found to be a satisfactory compromise for the fixed camera focal length and a one to two second filming sequence provided about six to ten feet of test film. Pertinent information as to target type, range, azimuth bearing etc.

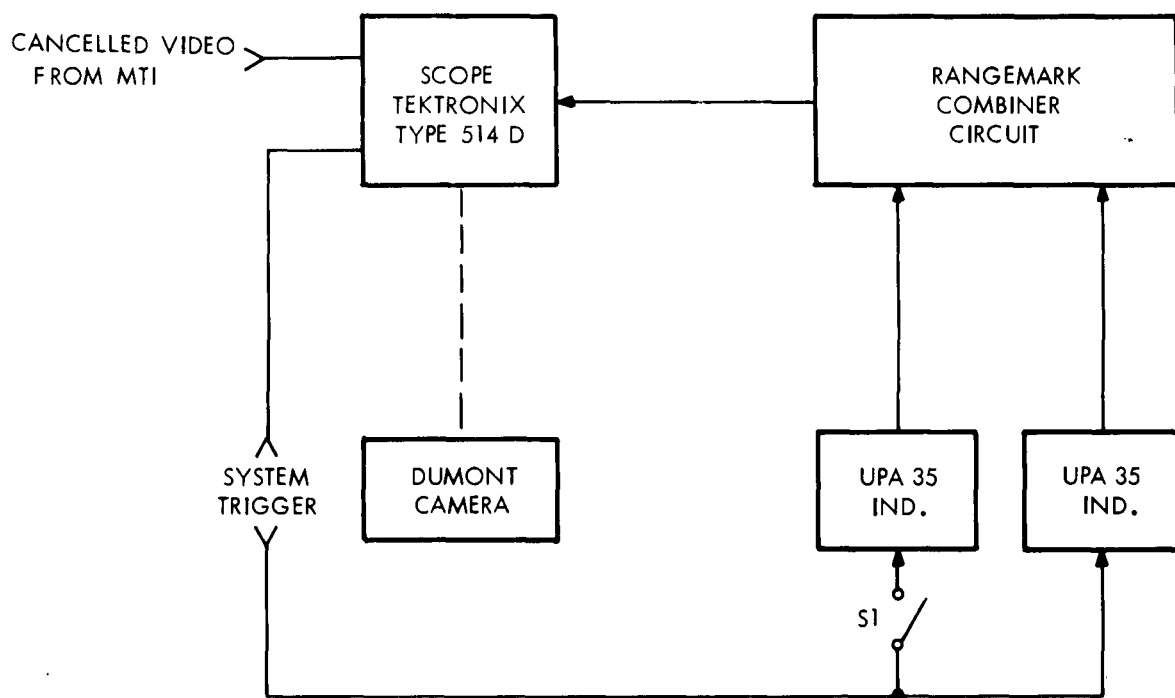


Figure A. Diagram of Range Mark Generation For Scope Used In High Speed Photograph

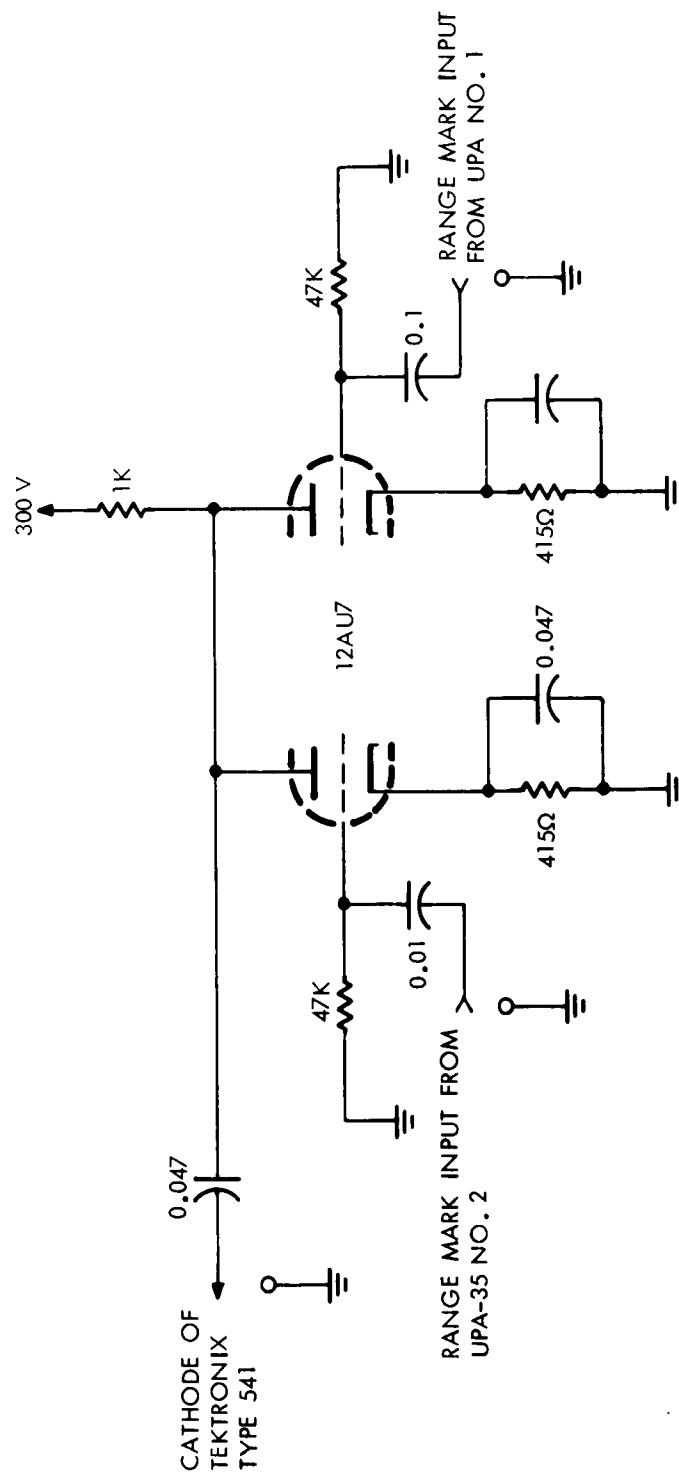


Figure B. Range Mark Combiner Circuit

became a permanent part of the film recording by means of a card indexing system. This record was photographed after each 35 mm target sequence. Great care had to be exercised during the filming to prevent any light leaks into the Tektronix oscilloscope due to the use of highly sensitive Tri-X type 35 mm film.

Boxcar Recording and Playback Technique

Figure D shows the equipment used for the storage and playback of the processed cancelled video information. The same video as that used for the high speed photography is fed into the boxcar demodulator circuit along with a system trigger. The trigger is used to drive a variable delay circuit which in turn generates a gate which gates a chosen 2 μ sec portion of the video into a pair of diode switches which allow the peak level of the video pulse to charge up a capacitor during each pulse period. This changing DC level is a pulse to pulse storage of the doppler modulation on the video. This regenerated doppler modulation is fed into a combiner stage where it is used to modulate a 5 KC sine wave signal. The doppler modulated 5 KC signal then passes to the Ampex FR 1102 recorder where it is stored. This recorder is operated at a speed of 7.5 inches/second.

Use of the dual Beam Tektronix scope as shown in Figure D permitted display of the cancelled video on one channel and the delayed "boxcar" gate on the other channel. It was then a simple matter to vary the gate and "boxcar" the desired segment of video.

Since the Ampex FR 1102 recorder had a dual track record capability the second channel was used to record pertinent voice comments related to the "Boxcar" data being stored. These comments proved invaluable during the data reduction phase since it afforded an excellent audio tabulation of the characteristics of the "angel" return under observation. During the "playback phase" of the "boxcar" data the information from the recorder output was fed into a diode detector circuit which "peeled off" the 5 KC signal and only the doppler modulation frequency thus remained. As can be observed in Figure D this information entered a Hewlett Packard Model 300A Wave Analyzer which could be tuned over the range of doppler frequencies. The selectivity of this unit for frequencies 20-300 cps amounted to 40 db below the maximum response point at 30 cps from the center frequency. For input frequencies of 300 - 600 cps (600 cps being highest usable frequency using the Dawes FPS/8 radar) the 40 db below maximum response point occurred at 145 cps deviation from the center frequency. Rectified DC output from the analyzer

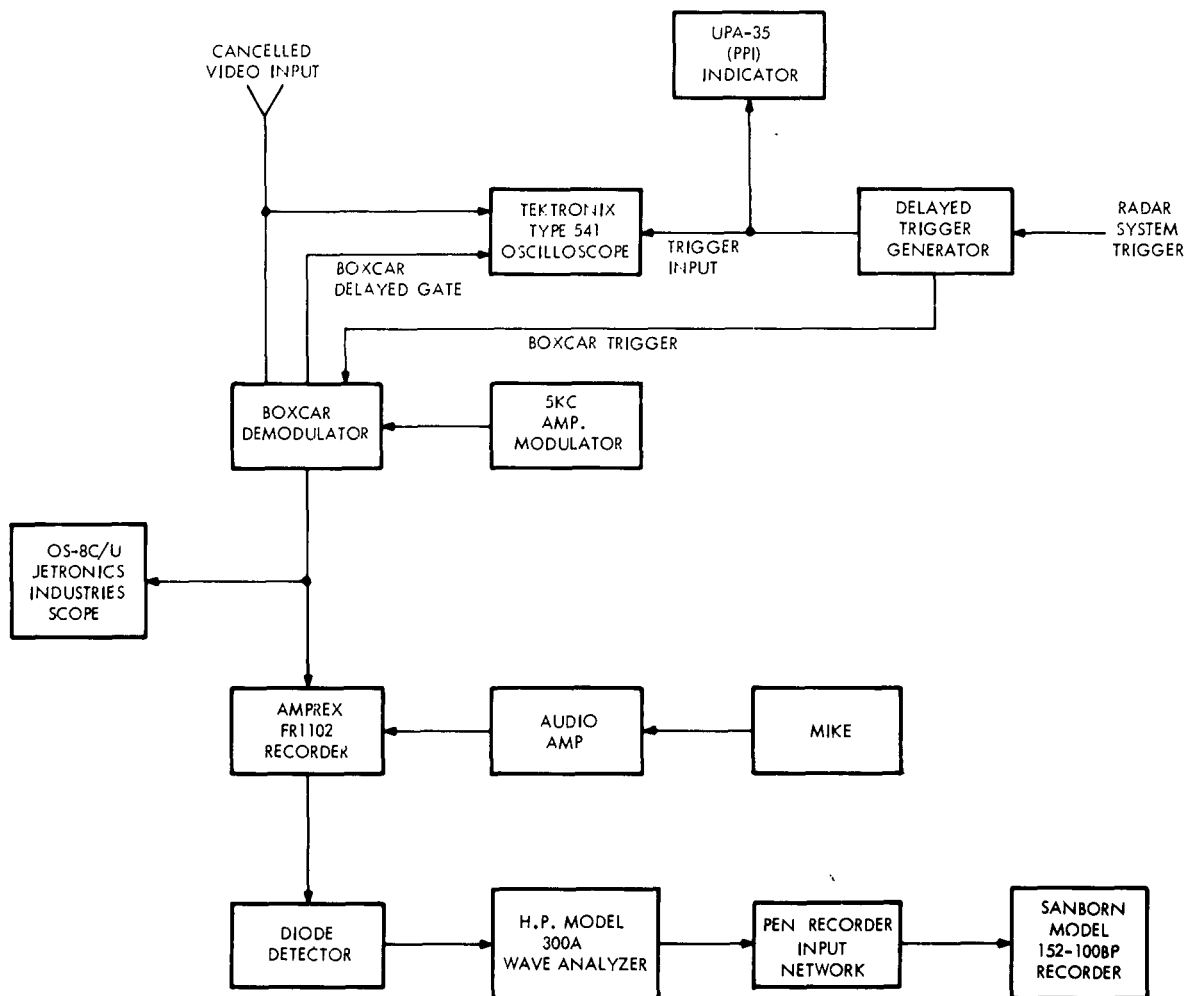


Figure D. Boxcar Record and Playback System

formed the input signal to the Pen recorder network. This network shown in Figure C consisted of 100 K damping resistors, a 0.25 μ fd integrating capacitor and 0.005 μ mf capacitors to provide high AC input impedance to the pre-amp.

The DC output voltage from the Sanborn DC preamplifier normally was reproduced by the pen recorder at a 1 MV/MM level at a paper speed of 2.5 MM/second. The average selected sample of playback "boxcar" doppler information lasted approximately 1 minute, however, usually 5-10 minutes of information might have been tape recorded. Also when it appeared during the recording cycle that a particular wide sample of cancelled video information indicated possible variation in doppler frequency throughout the "A" scope display, then several areas of the sample would be gated out and analyzed by "boxcar" technique. The output "boxcar" information from the demodulator was monitored by means of the OS-8C/U scope in order to maintain a level of signal to the Ampex recorder input that was within its linear recording range.

PPI Photographic Technique

PPI photographs were made during the study utilizing a dumont Polaroid scope camera mounted on a metal hood which was attached to a UPA-35 indicator. The camera focal length was a fixed distance after a shimming adjustment to give all the display information including the azimuth bearing ring. Time exposures were taken allowing a 360 degree rotation of the sweep deflection. The film for the camera consisted of Pola Pan 200 Type 42. Best results using this film required a lens opening of f4.0. Exact range location of a particular target undergoing boxcar recording became established on the PPI display by means of a delayed range strobe. This strobe was generated by feeding the variable delayed trigger into a normally unused video channel of the UPA-35 indicator.

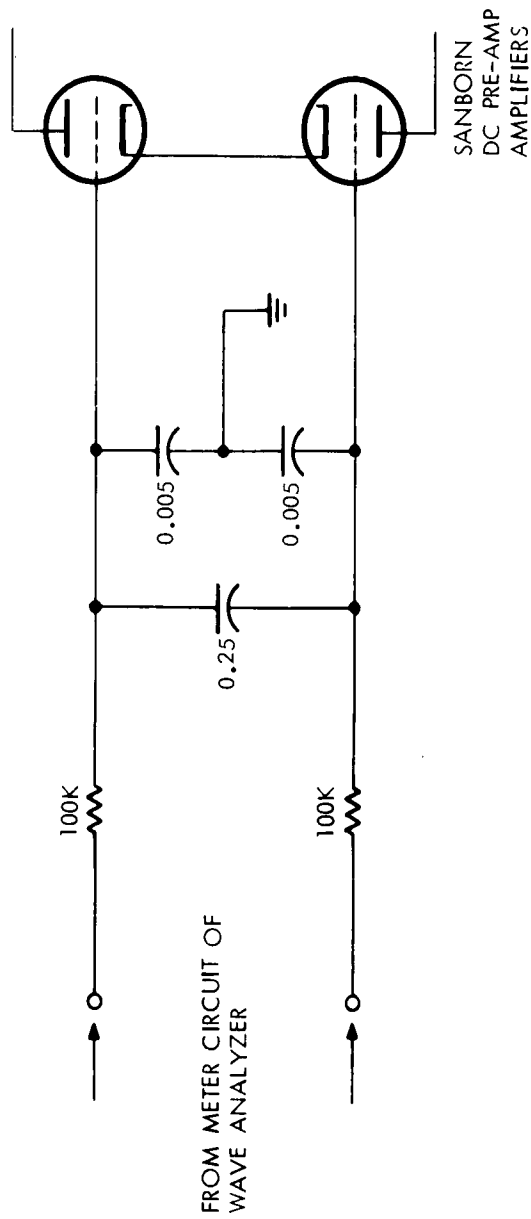


Figure C. Balanced DC Recorder Input — Circuit

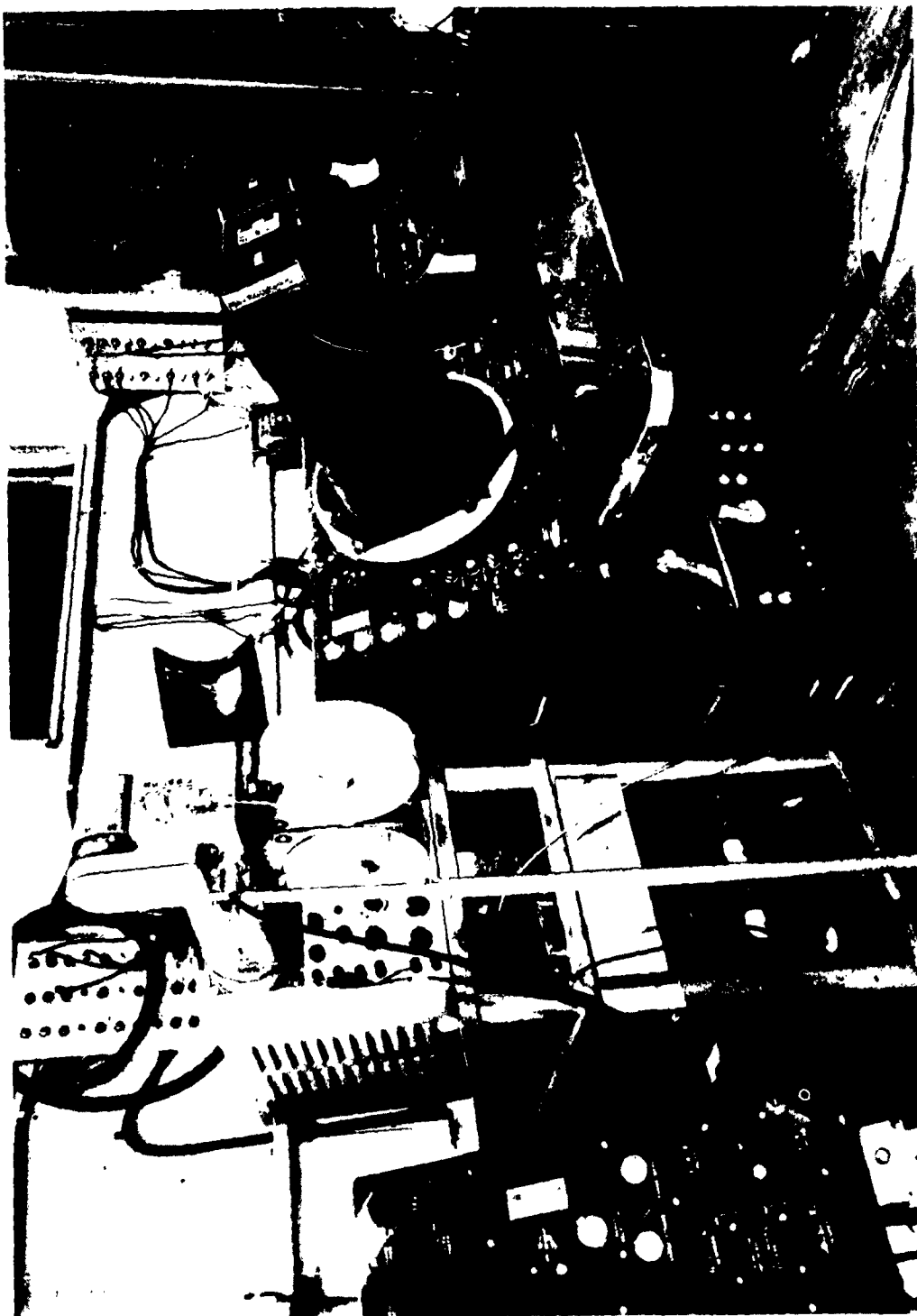


Figure E.

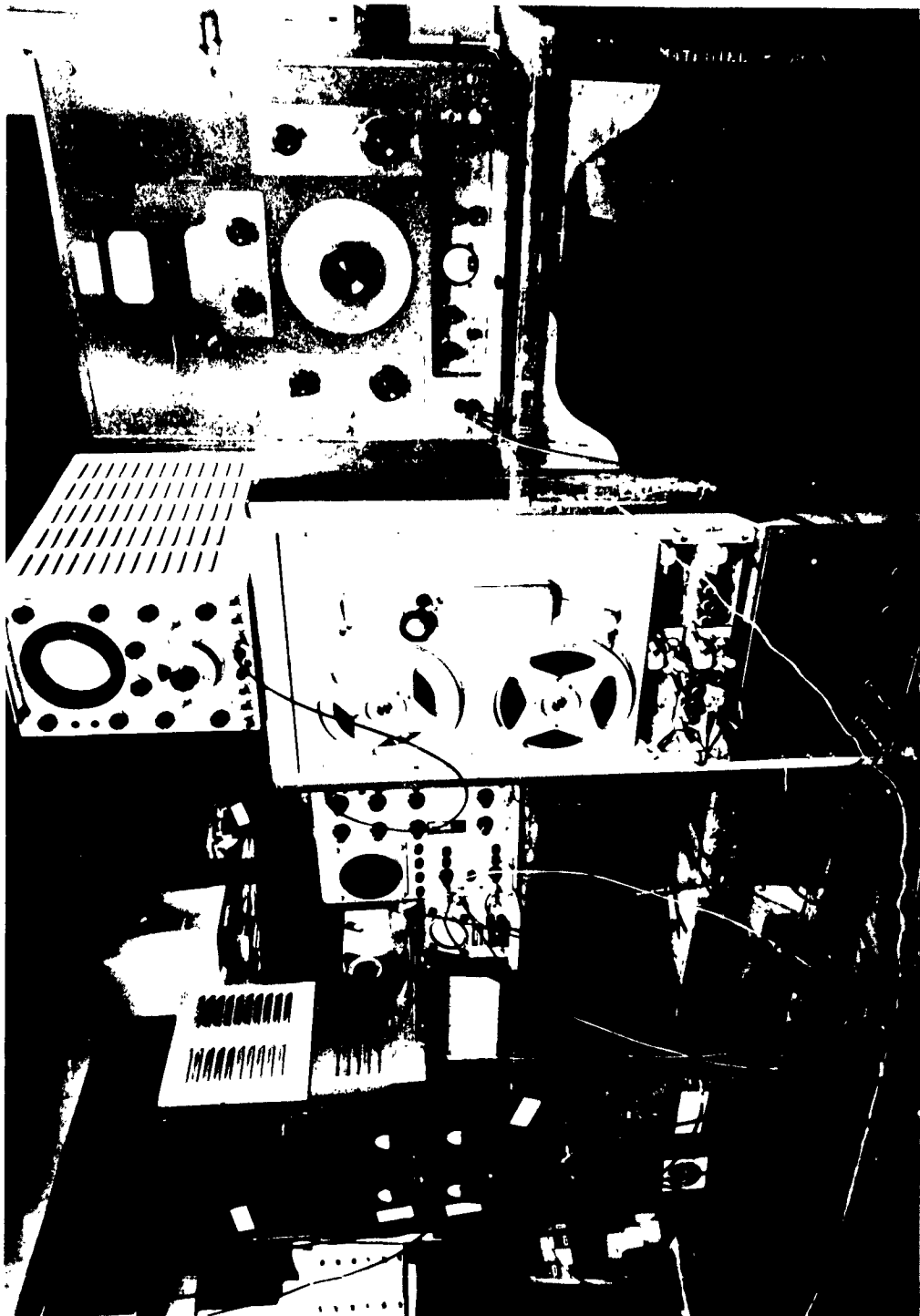


Figure F

III. CONDITION OF FPS-8 RADAR DURING DATA GATHERING PERIOD

Receiver Sensitivity

Since noise generation equipment was not available at the radar site relative sensitivity measurements were made on a day to day basis of "Minimum Discernable Signal Levels". Average readings throughout the angel study period (1961-1962) were as follows:

MTI Receiving System	102 dbm to -105 dbm
Normal Receiving System	106 dbm to -109 dbm

Marked decreases in MDS normally indicated a defect in either the main duplexer or the crystal protector located prior to the RF amplifier stage. This defect increased receiver path insertion loss either through a gradual degradation in quiescent transmission loss or a change in recovery time characteristics resulting in associated signal loss.

Cancellation Ratio (MTI System)

The MTI system cancellation ratio normally measured 30-35 db. This ratio could be preserved except during periods when defraction or refraction of the radiated energy occurred. During this time severe "ground clutter" of changing characteristics could be noted on a pulse to pulse basis and resulted in a general deterioration of the cancellation ratio between 2 and 10 miles in range around the Deer Island site.

Coherence of MTI System

Adequate coherence between transmitted and received pulse could be maintained during the course of the angel study. There were instances during periods of severe clutter where a portion of the clutter return coupled into the coho crystal mixer and passed on to the coho. Under these conditions the coho tended to phase lock to the clutter and not the MTI transmitter lock pulse.

Duplexer Recovery Time

The measured recovery time of the polarization twist duplexer in the Fort Dawes FPS-8 radar was 53 microseconds at the 3 db point. Therefore targets returns at 4.29 nautical miles would be attenuated by 3 db as compared

to those out in the 0 db region of the recovery curve. Proper radar alignment and a recovery time slope previously described permitted aircraft targets to be observed at a minimum range of 1.9 nautical miles. It was imperative that this 53 μ sec recovery time be maintained since if it were allowed to deteriorate then low level "angel" return would become attenuated and result in a loss of valuable data during the study period.

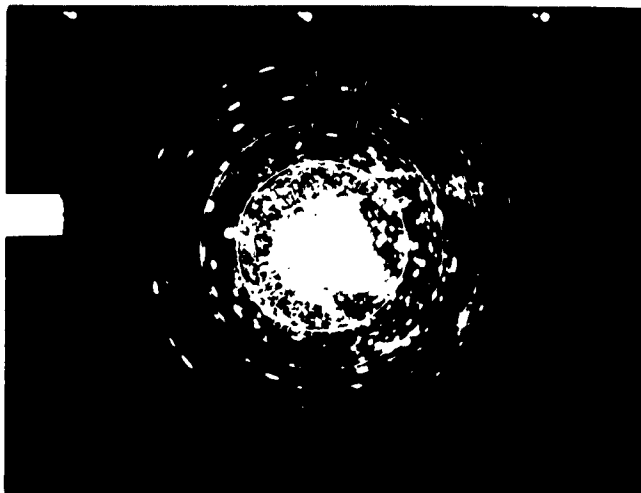
IV. DATA GATHERED AND RESULTS

Single Type Angel Return

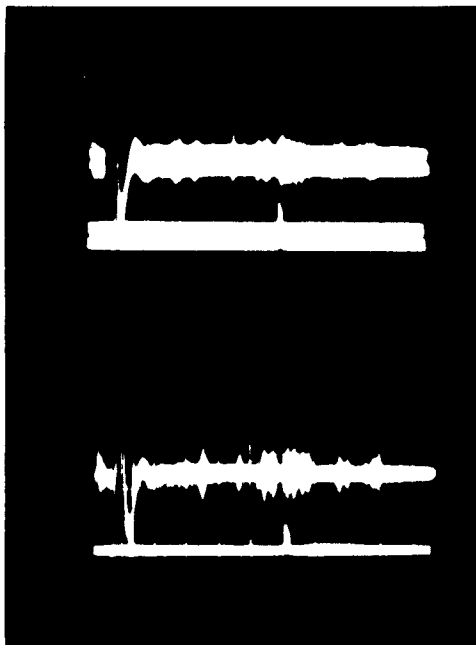
This particular type of interference can be described as small, circular, "blob" like targets which average about half the size of an aircraft return in azimuth and about half the size in range extent. Time duration of single type "angel" return has been noted to vary from 15 seconds or so to as long as 10-15 minutes. During periods of activity, the "angel" targets did not appear to move in range or azimuth on the PPI displays, but rather fade out and reappear in essentially their original position. Observation of expanded range "A" scope displays while search-lighting on single targets substantiated the fact that no movement was apparent. As received on the "A" scope, these targets were noted to rise to full amplitude and then either slowly or rapidly decrease in level into the noise and then after a short period of time build up again in intensity to their original signal level. All single type "angel" return appearing on the radar displays occurred over water. Active periods produced "angel" targets which could appear anywhere from 5-20 miles in range over a 100° quadrant in azimuth. At times, sufficient numbers appeared that this entire area would be occupied with scattered returns. During 1961 single type activity was present during the months of August and September. In 1962 the months of noted activity were June, August, September and October. The weather conditions which proved favorable to single type "angel" buildup were generally calm wind, high humidity, hazy, temperatures 85° - 90°. Reference to the photographs on single type "angel" return in this report show that these signals, both in the "A" scope and high speed films, are similar in appearance to aircraft return. The "A" scope photograph (see Single Type "Angel" Display Photo Figure 1) also reveals how multiple single "angel" targets can be grouped very closely in range along a fixed azimuth vector. The high speed film clip on the single type return shows an average apparent doppler frequency of 86 cycles per second. The box-car data plots on this target sample (Figures 2 and 3) indicate a peak in the doppler modulation of between 80 cycles to 90 cycles per second. The doppler frequency data plots for this single type "angels" were recorded using a 42 second magnetic tape sample. All of the single type "angel" targets observed and box-car recorded at the Fort Dawes site had spectral center frequencies between 66 and 198 cycles. The greater percentage were centered at or near 100 cycles and possessed a narrow bandwidth. These results are in agreement with the work done by AIL Laboratories in 1956.

Single Type Angel Displays

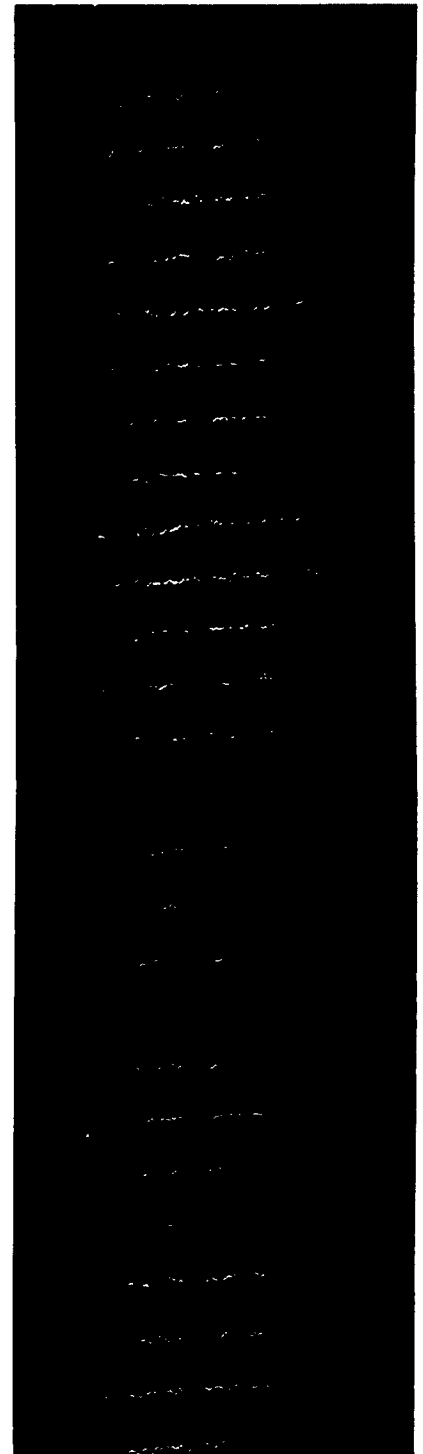
5MI 10MI 15MI 20MI
| | L |



MTI Presentation of Single Type Angel Return East of the Site. Each Range Mark is a 5 Mile Increment.

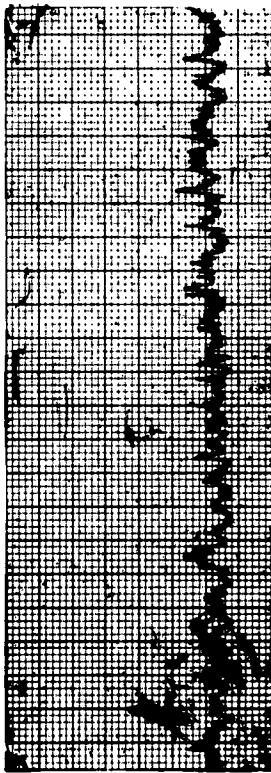


"A" Scope Presentation of Single Type Angel Targets Located East of the Site. Sweep Speed 20 μ sec/cm. Antenna Searchlighted at 89° Azimuth.

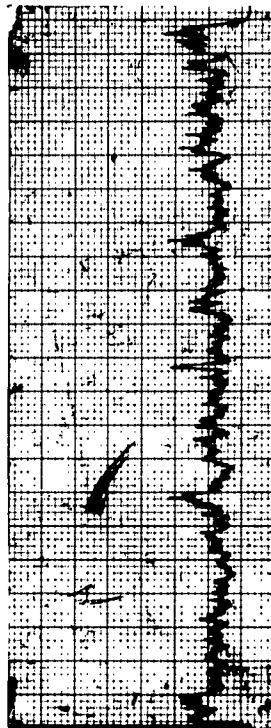


Single Type Angel - High Speed 35MM Cancelled Video Display.

Figure 1. Single Type Angel Displays



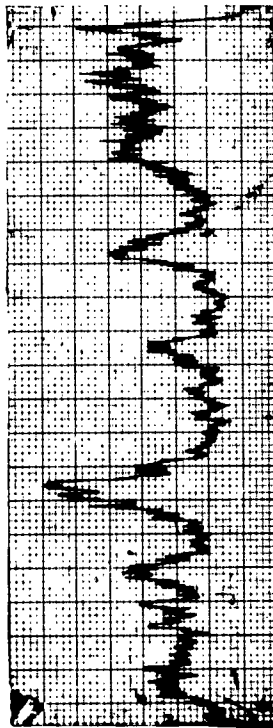
40~



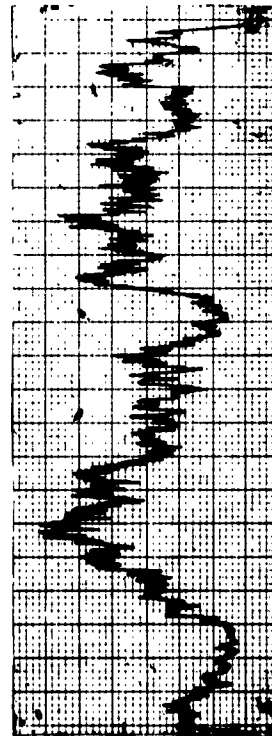
50~



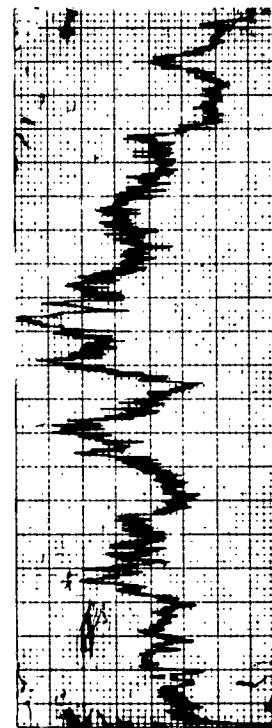
60~



70~



80~



90~

Figure 2. "Boxcar" Data of Single Type Angel Return

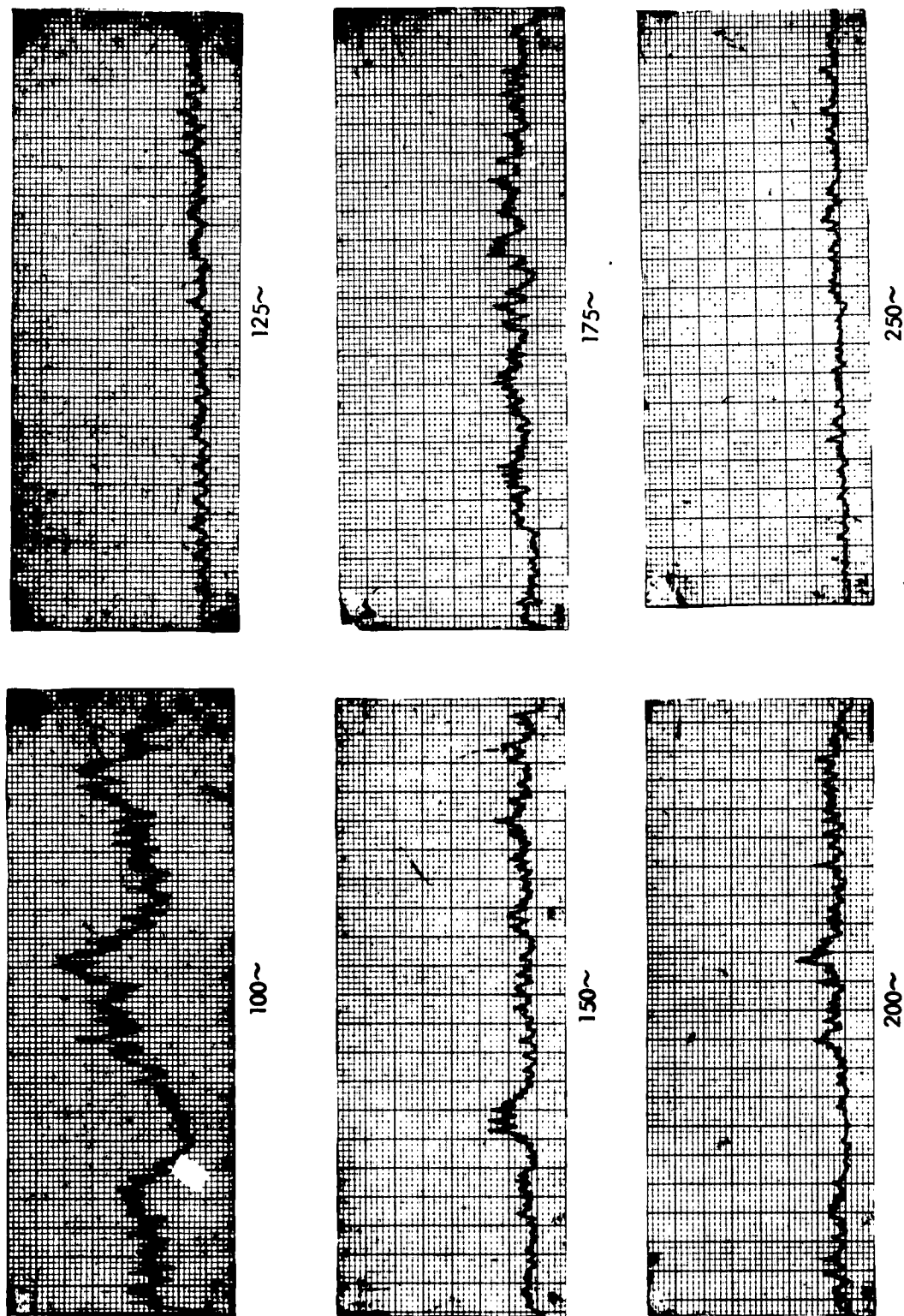


Figure 3. "Boxcar" Data of Single Type Angel Return

Group Angel Return

The single "angel" return discussed in the previous section consisted of individual separate targets distributed in groups over an area. The group "angel" has been given this name because the return as it appeared on the PPI looked like a target which was extended in range for many pulse widths along a single azimuth bearing, however, when examined on an "A" scope where more detail could be observed, the return was seen to be made up of individual returns spaced very closely together in range. Smearing on the PPI caused the blending of these individual returns into a more or less solid blob.

Group "angel" activity as observed during the 1961-1962 study at Fort Dawes consisted of intense targets occurring at an azimuth bearing of approximately 70°. These targets were normally quite intense on the MTI, PPI displays as can be seen in the PPI Photo Figure 4 included in this report. Although the greatest activity usually occurred between 7-20 miles they were on occasion noted at 40-50 mile ranges. Time duration of a group angel display was usually 4-8 hours. The geographic location of these targets at 70°, 7-50 miles, was interestingly over salt water. Weather conditions during periods of group "angel" activity were comparable to those under which single type "angels" occurred. There were times while noting group "angel" activity when beam defraction or refraction became noticeable by the appearance of land masses beyond the radar horizon. Group "angels" were present on the PPI displays at times when no single type "angels" made their appearance. The "A" scope display of the group "angels" indicates the signals to be almost noiselike in character. The high speed 35 mm film clip on the other hand shows the target portions to be shaped similar to aircraft cancelled video return, and to be changing at a rapid random doppler rate. The "boxcar" frequency analysis on a portion of this group "angel" sample (Figures 5, 6, and 7) confirmed the random nature of the doppler modulation and indicated that the modulation was quite broadband, extending from 40 to 400 cps.

Further examination of the high speed film revealed that although the doppler modulation was random, that adjacent 2 μ sec portions of the target tended to vary in the same manner on a pulse to pulse basis.

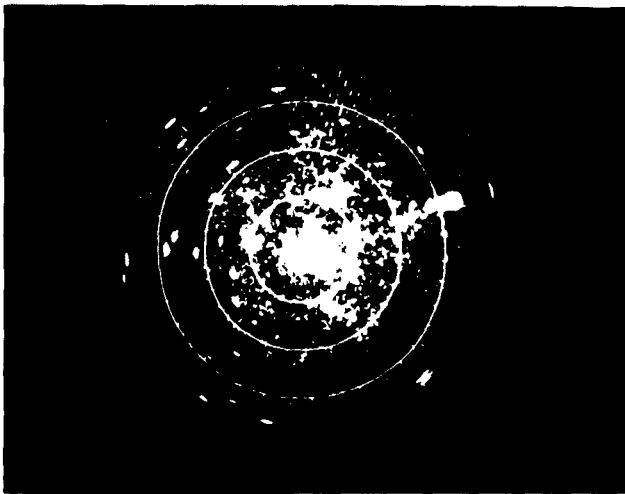
Miscellaneous Unknown Return

The MTI display in Figure 9 containing what we have defined as a "streak" target is typical of the activity noted usually early in the morning during periods

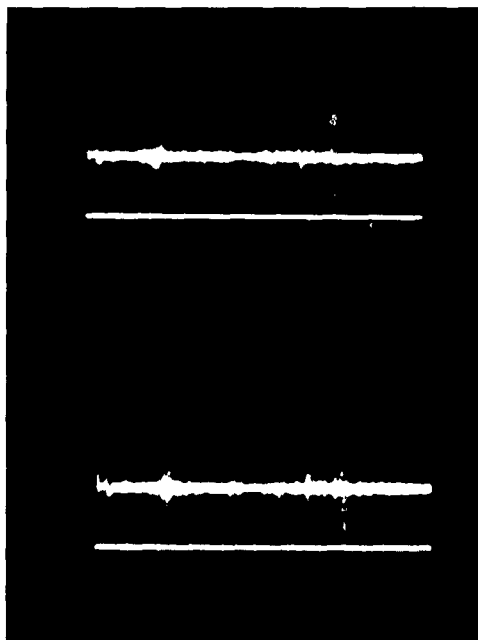
Group Angel Displays

5 MI

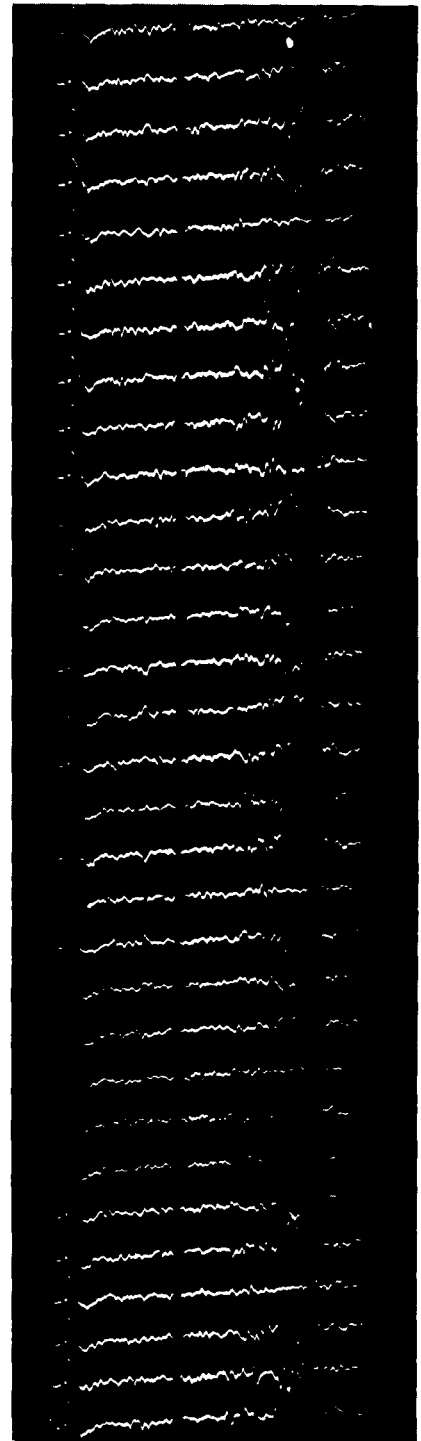
10 MI



MTI Presentation of Group Angel Activity at 71° Azimuth Bearing, 10-17 Mile Range. Each Range Mark Is a 5 Mile Increment.

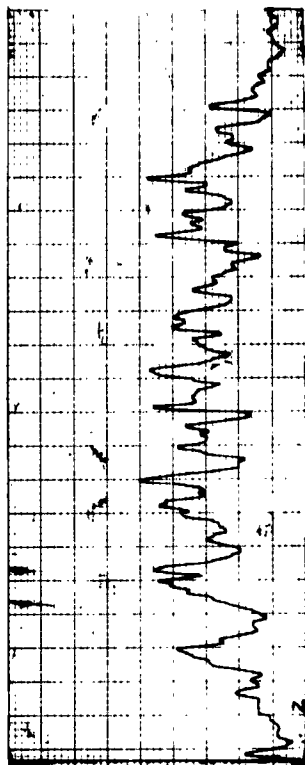


"A" Scope Presentation of Group Angel Activity at 71° Azimuth Bearing. Sweep Speed 50 μ sec/cm.

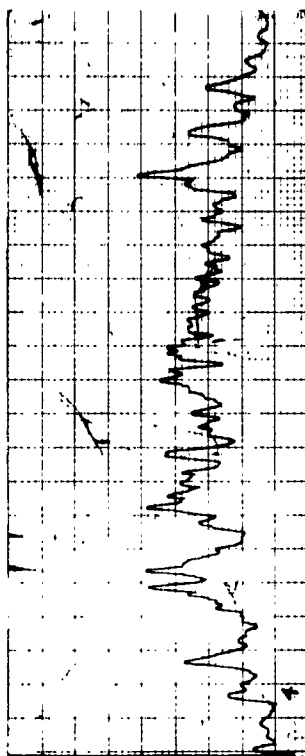


Group Angel - High Speed 35MM Cancelled Video Display

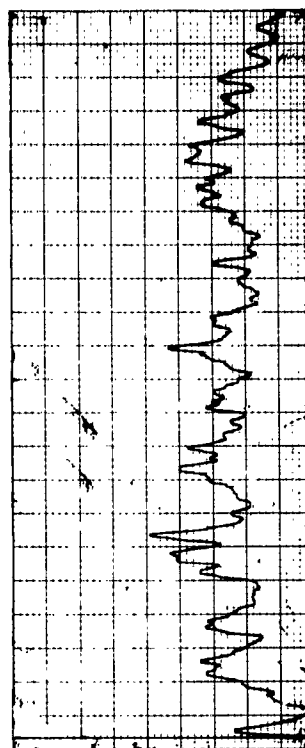
Figure 4. Group Angel Displays



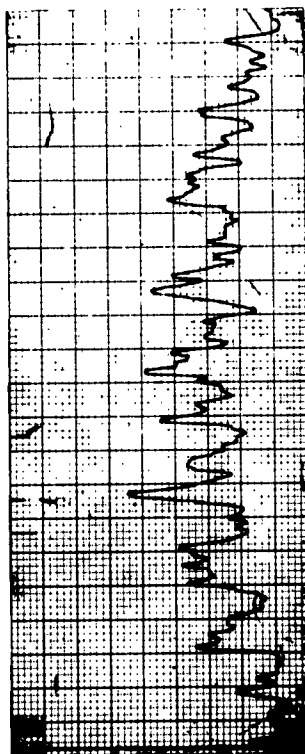
50~



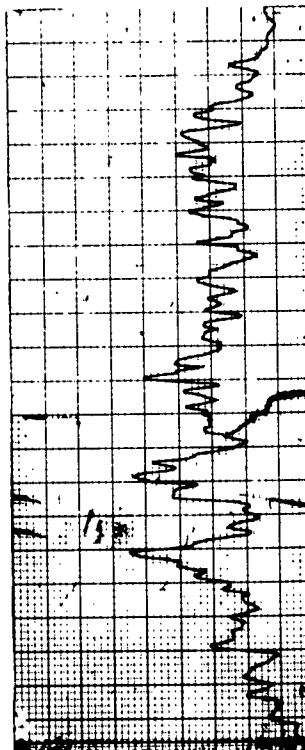
70~



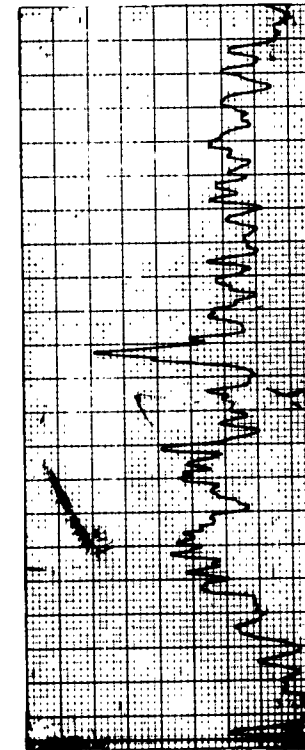
90~



40~

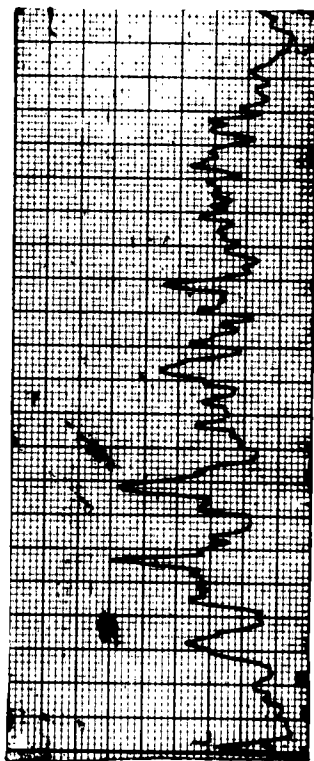


60~

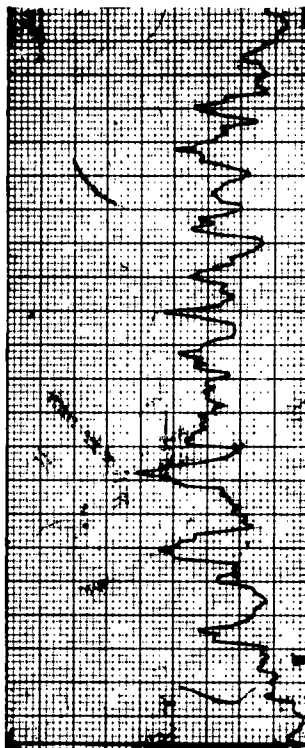


80~

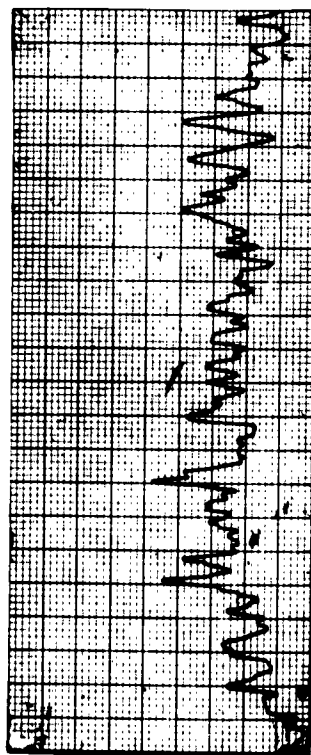
Figure 5. "Boxcar" Data of Group Angel Return



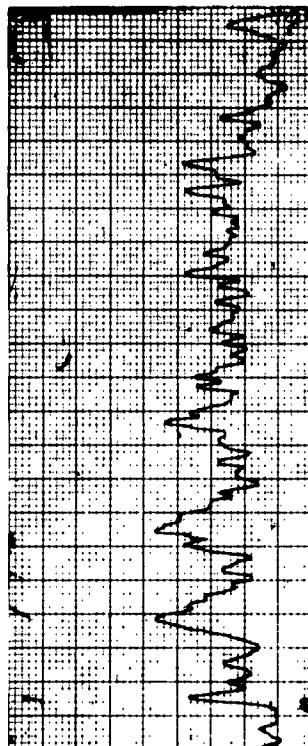
100~



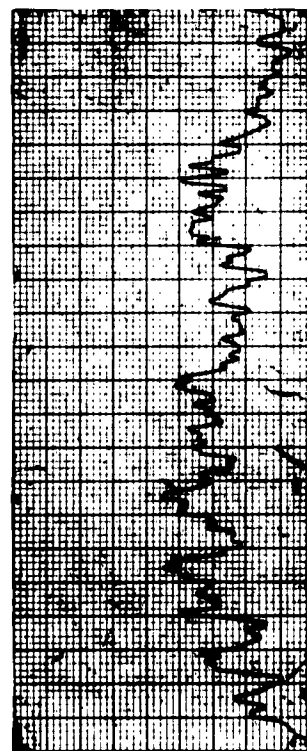
125~



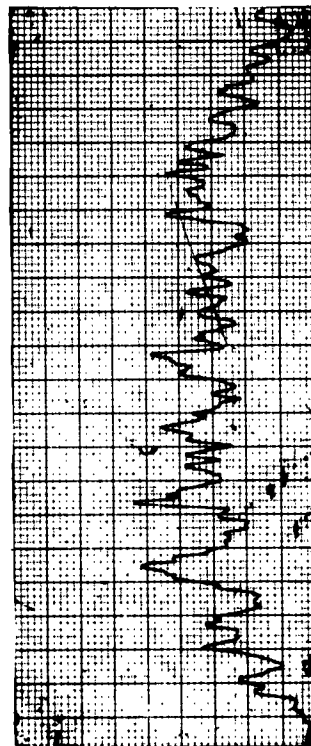
150~



175~



200~



250~

Figure 6. "Boxcar" Data of Group Angel Return

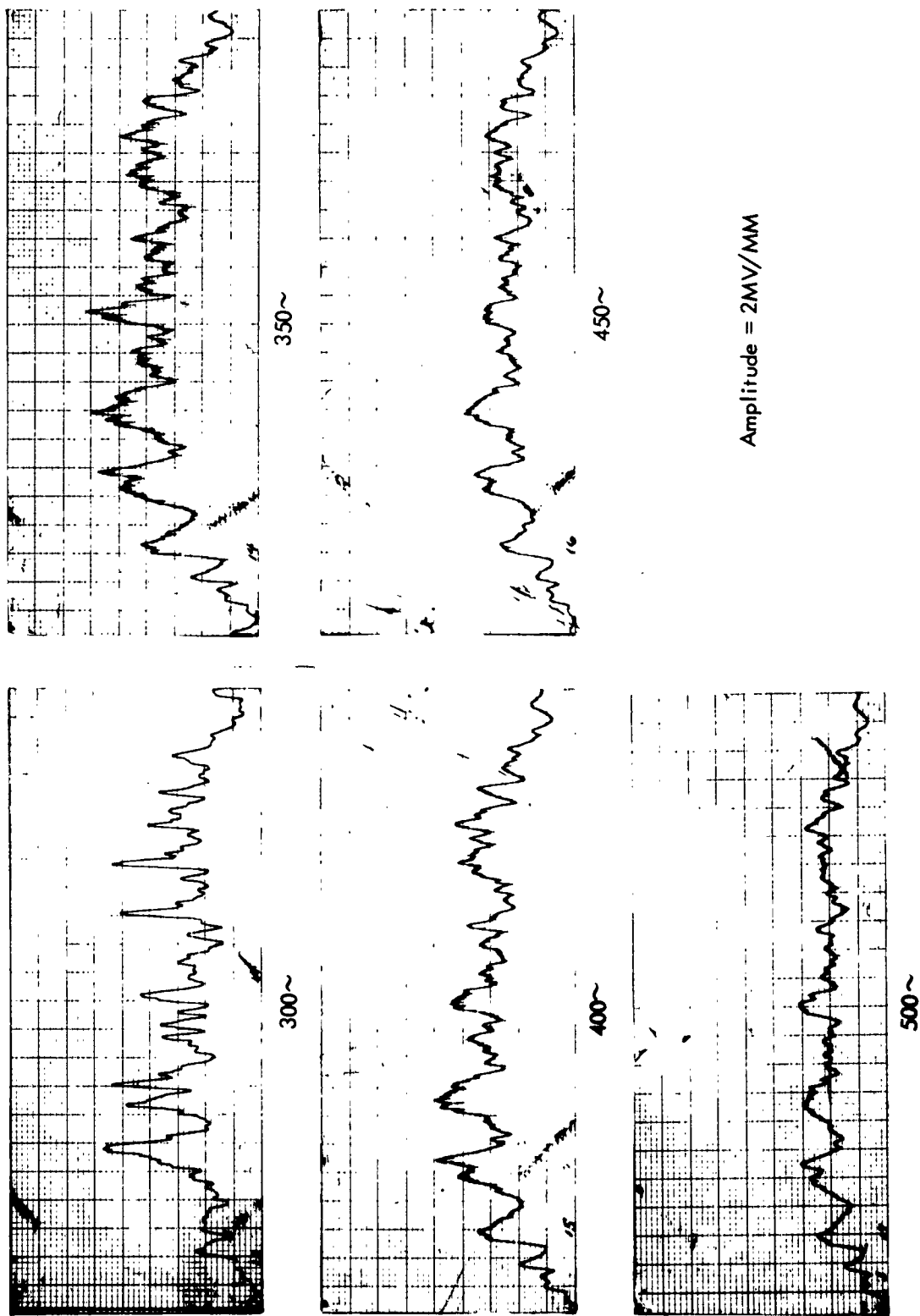


Figure 7. "Boxcar" Data of Group Angel Return

High Speed 35MM Bi-Polar Cancelled Video Return

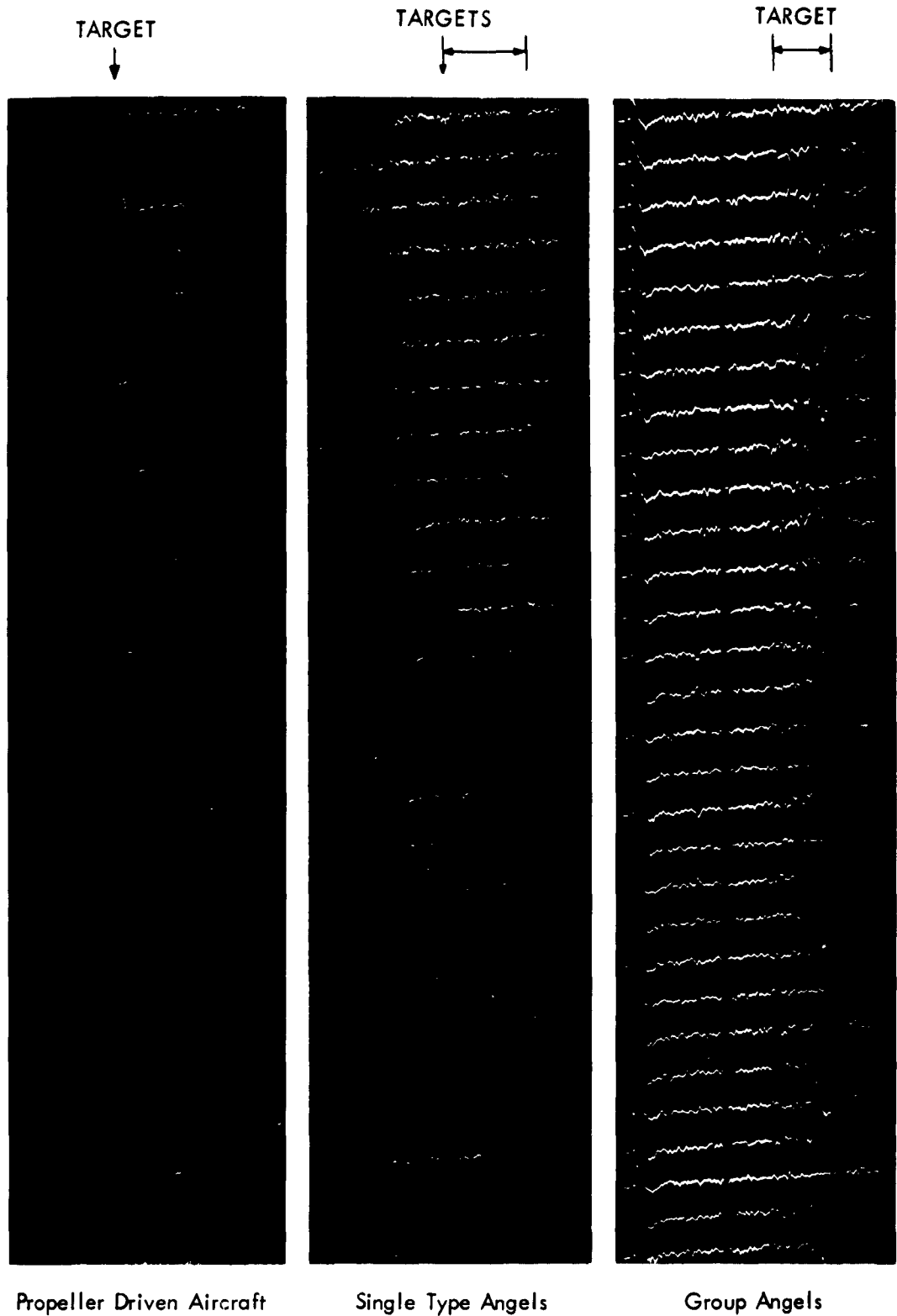
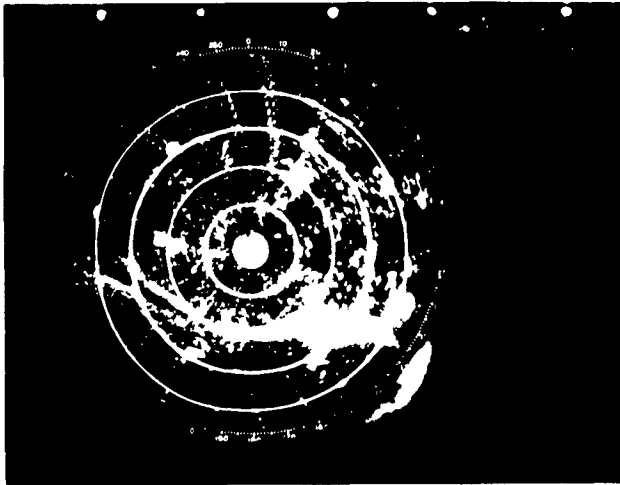


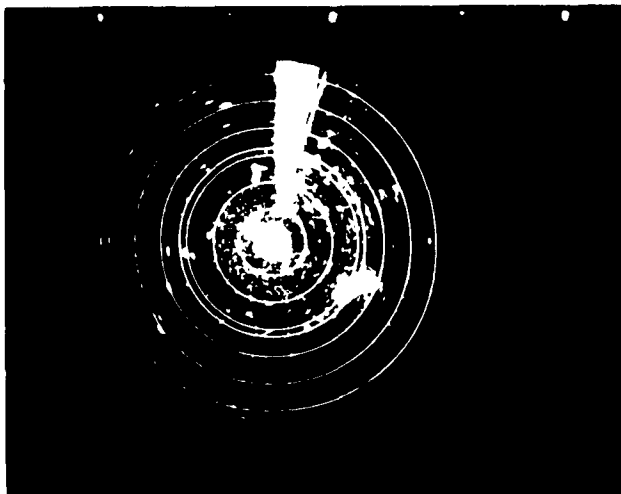
Figure 8. High Speed 35 mm Bi-Polar Cancelled Video Return

Miscellaneous Unknown Displays

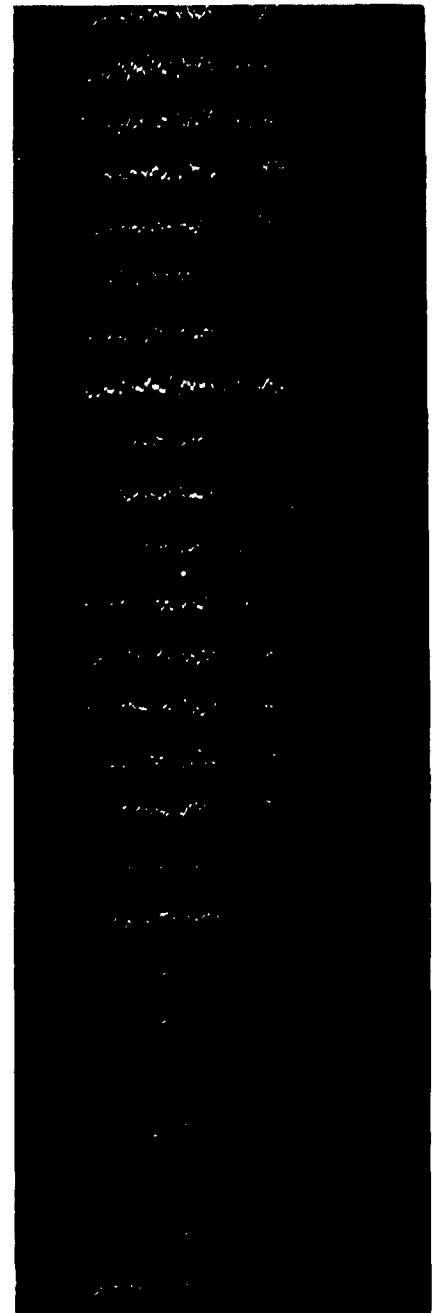
5 MI 10 MI 15 MI



MTI Presentation of Unknown "Streak" South East of the Site. Each Range Mark is a 5 Mile Increment.



MTI Presentation of Unknown "Clump" Return South East of the Site at 15 Mile Range. Each Range Mark is a 5 Mile Increment.



Unknown "Streak" - High Speed 35MM Cancelled Video Display
(Antenna "Searchlighted" at 140° Azimuth Bearing)

Figure 9. Miscellaneous Unknown Displays

of sudden area temperature rise. This particular display disappeared in approximately 45 minutes from the time of first observation. The PPI photograph in Figure 9 was taken near the peak intensity of the signal return and shows that it extends east to west for almost 35 miles. Although the 35 mm high speed film clip in Figure 9 shows a similarity to that for the Group "angel" return in Figure 4, the "boxcar" data for the streak return indicated a narrow doppler modulation spectrum (30 cps) which peaked at 100 cycles per second. The "clump" return shown also in Figure 9 was noted on another date during similar rapidly changing temperature condition. In this photograph "noise jamming" can be seen coming in from north of the site.

Weather Return

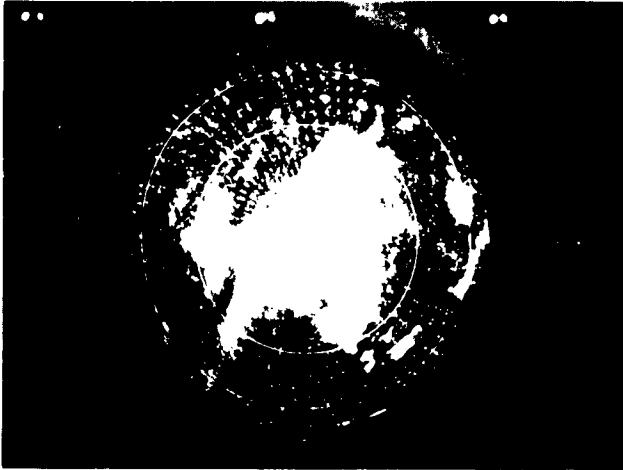
A typical area weather display taken during a fall rain storm can be seen in Figure 10. The "A" scope delayed presentation reveals the intense noiselike character of the Bi-Polar cancelled video signal. Sweep by sweep high speed filming shown also in Figure 10 indicates a random changing doppler modulation rate, however, the 2 μ second portion of the video which was gated out by the boxcar circuit gave doppler modulation peaks at 20, 100, and 125 cycles. At these frequencies the bandwidth appeared to be quite narrow as can be evidenced by the data plots in Figures 11 and 12. Typical samples of weather data taken during the fall of 1961 and spring, summer, fall of 1962 had doppler modulation bandwidths ranging from 95 cycles to 140 cycles. Although these bandwidths are somewhat narrower than for the group "angels", they still display random noise-like characteristics on "A" scope photographs and high speed 35 mm film samples. These data samples had broad maximum frequencies in the range from 40 cycles to 150 cycles.

Aircraft Signal Samples

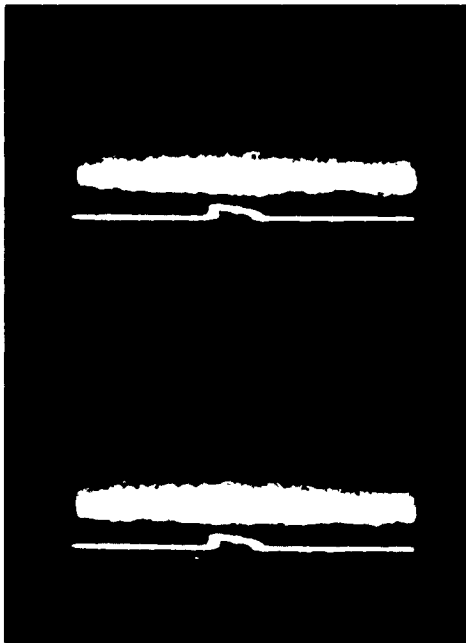
Several aircraft signal samples were accrued during the angel study for comparison with data taken on the various "unknowns". Figure 8 shows a typical propeller driven aircraft return from a target in the vicinity of Logan Airport, Boston, Mass. "Boxcar" data on this target can be seen in Figures 13, 14, and 15.

The analysis of the "boxcar" data indicates a broad range doppler modulation peaks from 40-45 cycles with lesser peaks at 90 and 300 cycles. It appears that we have a mixture of doppler frequencies caused by aircraft motion and propeller modulation.

Weather Displays

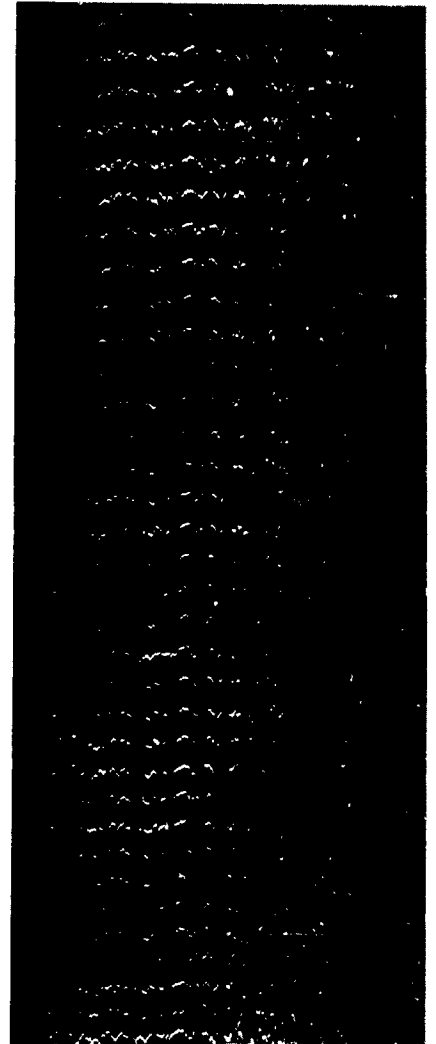


MTI Presentation of Weather Return in the Boston Area. Each Range Mark Is a 10 Mile Increment.



"A" Scope Presentation of Weather Return.
Sweep Speed 2 $\mu\text{sec}/\text{cm}$.

5 MI 10 MI 15 MI
| | |



Weather - High Speed 35MM
Cancelled Video Display

Figure 10. Weather Displays

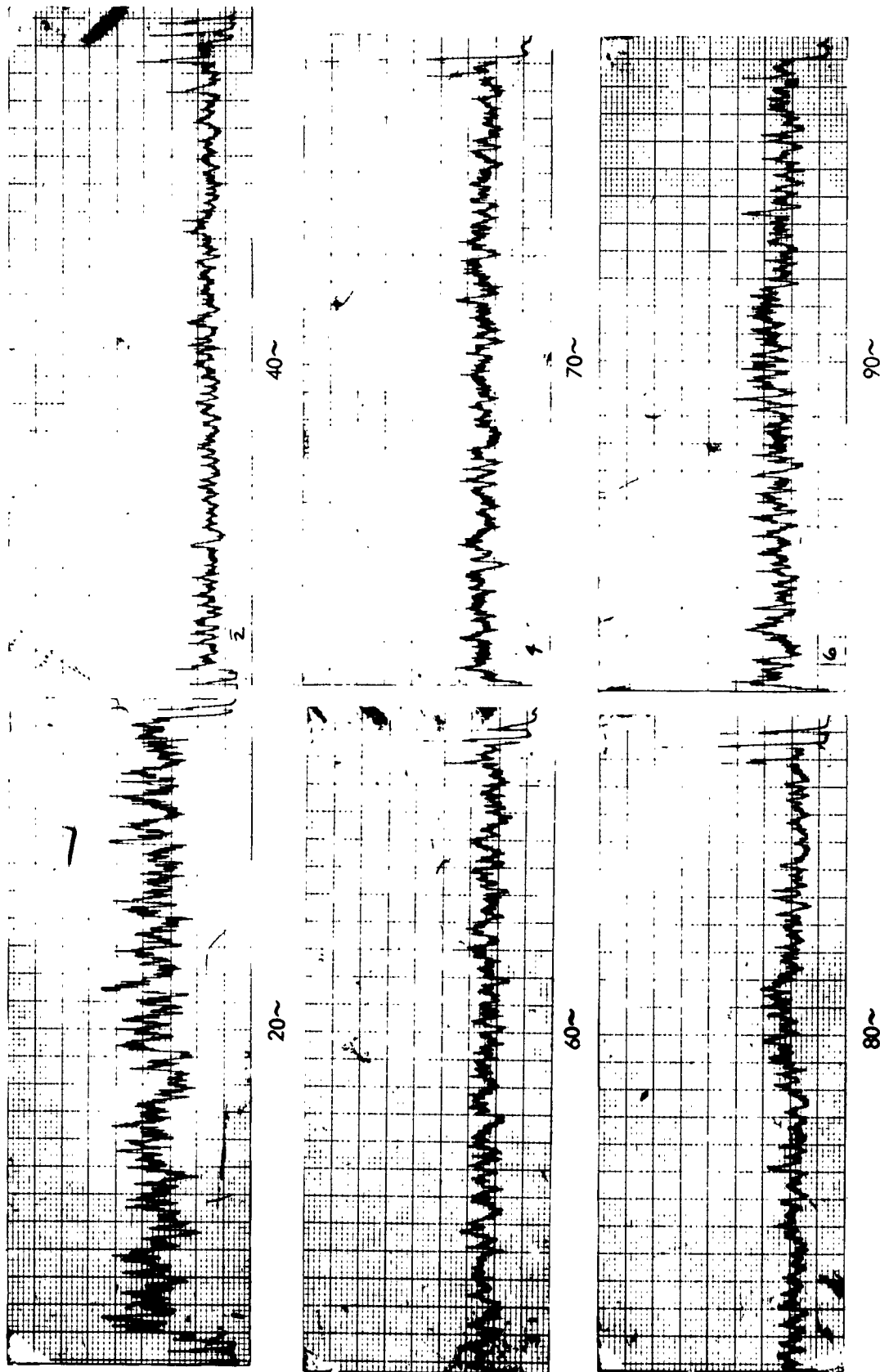
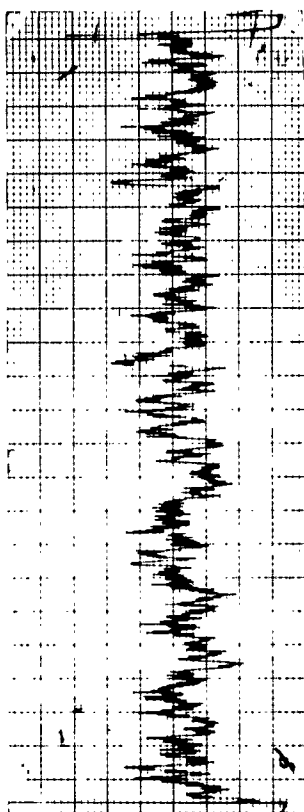
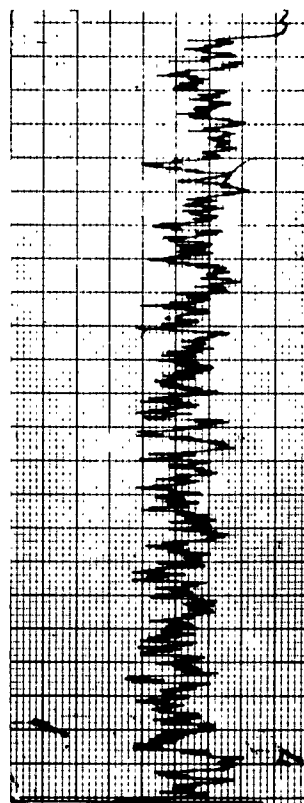


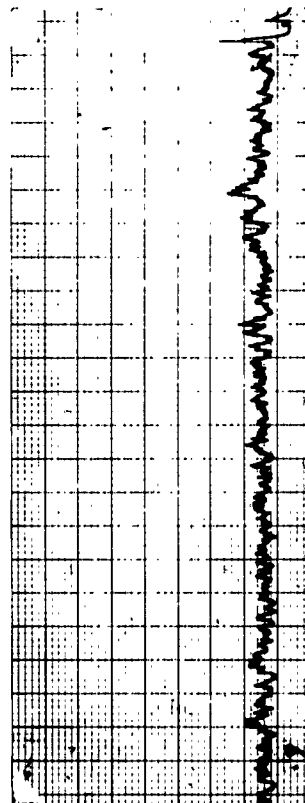
Figure 11. "Boxcar" Data of Weather Return



125~



100~



150~

Amplitude = 1MV/MM

Figure 12. "Boxcar" Data of Weather Return

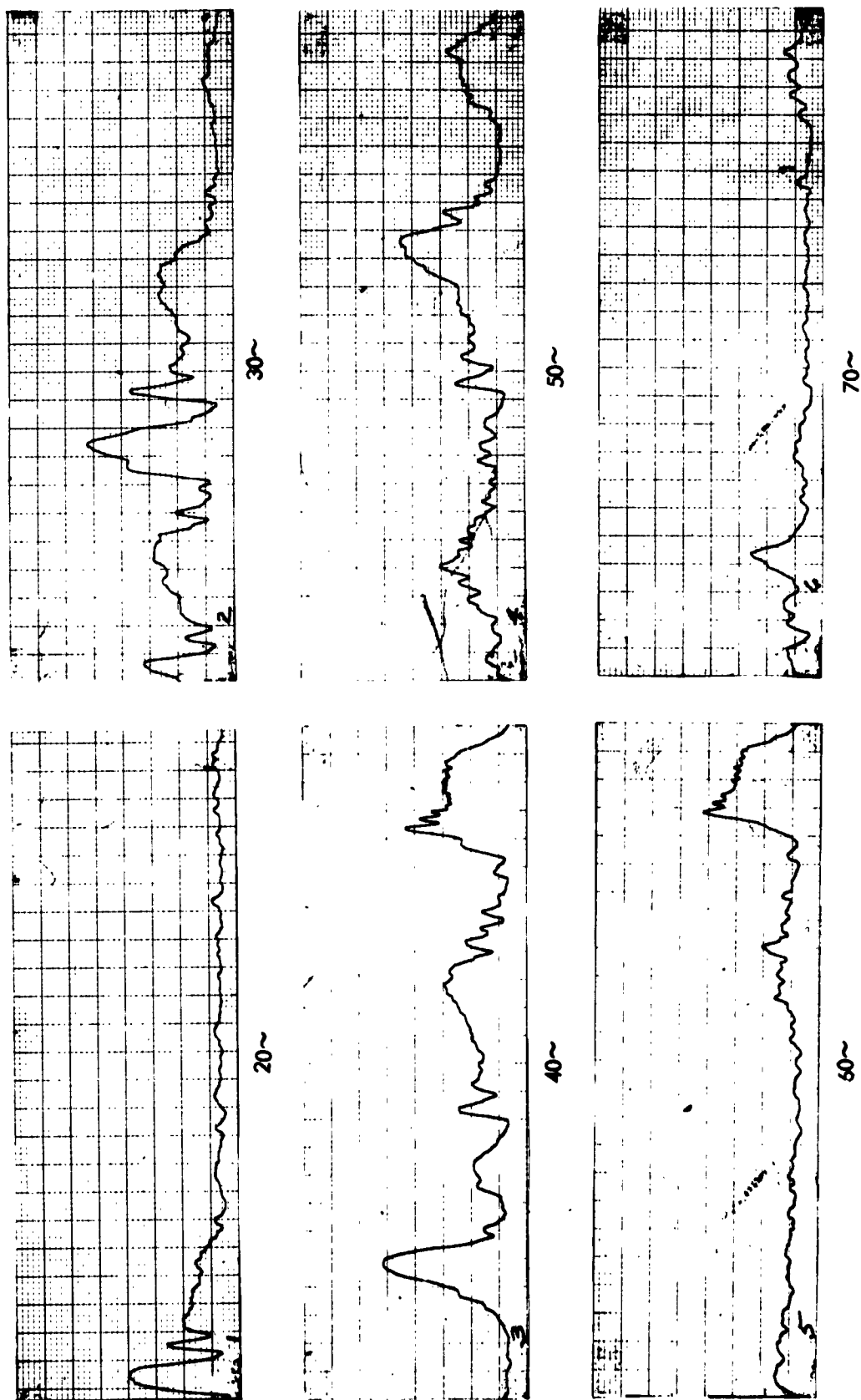


Figure 13. "Boxcar" Data of An Aircraft Return

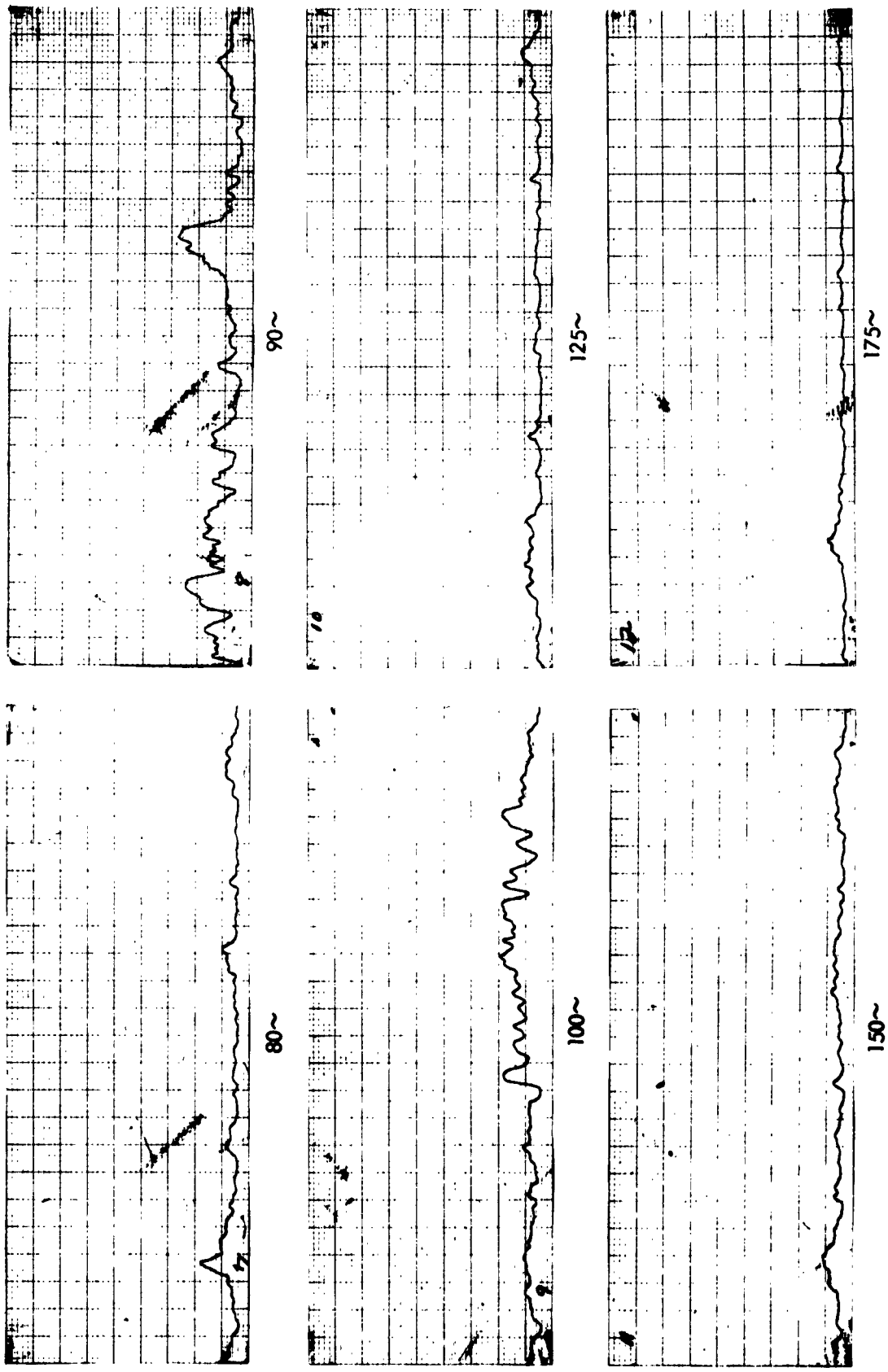
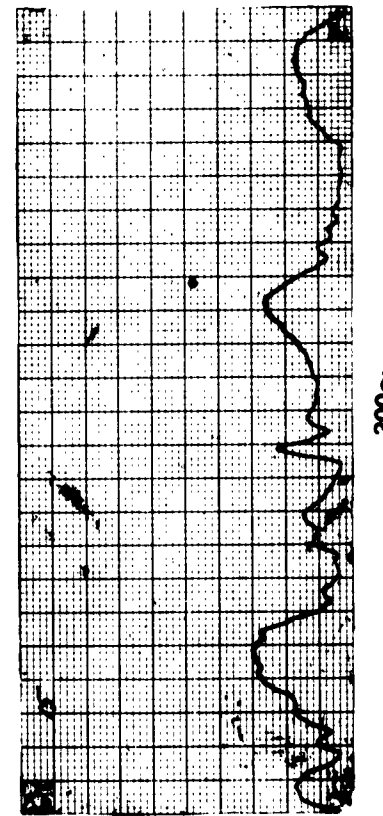
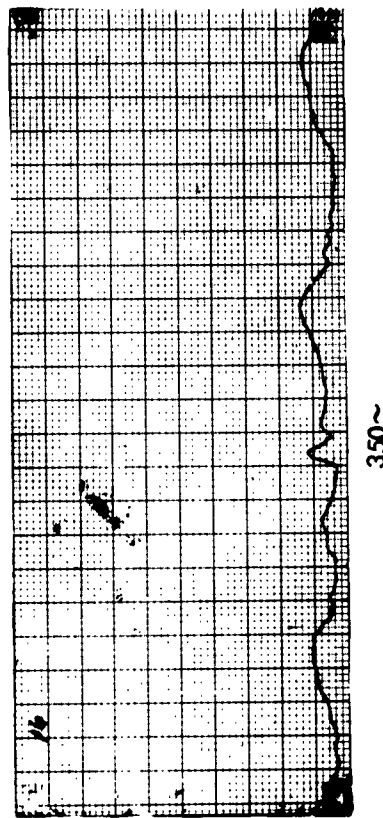
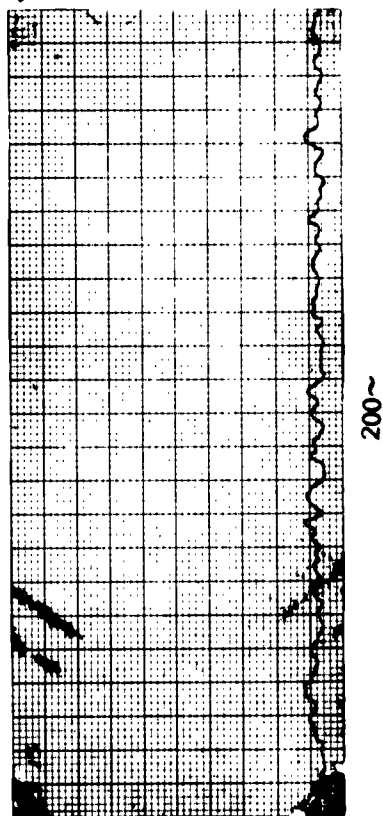
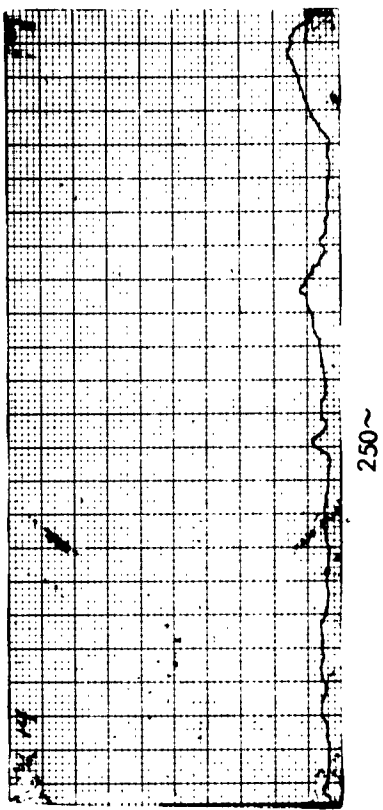


Figure 14. "Boxcar" Data of an Aircraft Return



Amplitude = 2MV/MM

Figure 15. "Boxcar" Data of an Aircraft Return

U. S. WEATHER BUREAU LOCAL CLIMATOLOGICAL CONDITIONS
DURING "ANGEL" OBSERVATION PERIOD FOR SAMPLES DISCUSSED IN THIS REPORT

Angel Type	Sky Condition	Ceiling	Weather and/or Obstruction to Vision	Station Pressure	Temperature Dry Bulb (°F)	Relative Humidity	Dew Pt. (°F)	Wind Direction	Wind Speed (mph)	Visibility
"Single"	Scattered Clouds	Unlimited	Smoked haze	29.89	72	49	52	SSW	9	13 miles
"Group"	Broken Clouds	Unlimited		29.95	85	41	59	SSE	13	13 miles
"Streak"	Scattered Clouds	Unlimited	Smoked haze	29.69	63	67	52	S	14	5 miles
"Clump"	Scattered Clouds	Unlimited		30.34	53	54	37	E	10	12 miles

TABULATION OF ANGEL SAMPLE CHARACTERISTICS

DATA RECORDED DURING 1961-1962 PERIOD

Sample No.	Angel Type	Average Time Duration of Display	Average Time Duration of Individual Targets	Apparent Center Doppler Frequency	Doppler Frequency Bandwidth	Target Average S/N Ratio
1	Single	4 hours	2 minutes	125 cps	50 cycles	10 db
2	Single	2 1/2 hours	1-2 minutes	90 cps	20 cycles	6 db
3	Single	2 1/2 hours	1-2 minutes	100 cps	20 cycles	6 db
4	Single	2 hours	10-15 minutes	90 cps	20 cycles	
5	Single	2 hours	10-15 minutes	90 cps	20 cycles	
6	Single	2 hours	5-10 minutes	100 cps	20 cycles	9.5 db
7	Single	2 hours	5-10 minutes	107 cps	10 cycles	9.5 db
8	Single	2 hours	5-10 minutes	55 cps	50 cycles	9-10 db
9	Single	2 hours	5-10 minutes	70 cps	30 cycles	
10	Single	1 1/2 hours	1-2 minutes	80 cps	20 cycles	6 db
11	Single	1 hour	1-5 minutes	100 cps	35 cycles	9.5 db
12	Single	1 1/2 hours	10-15 minutes	100 cps	20 cycles	6 db
13	Single	1 1/2 hours	10-15 minutes	100 cps	20 cycles	6 db
14	Single	1 1/2 hours	10-15 minutes	50 cps	20 cycles	6 db
15	Single	1 1/2 hours		90 cps	20 cycles	2.5 db
16	Group	4 hours	4 hours		40-400 cycles	14.5 db
17	Group	4 hours	4 hours	50 cps	20 cycles	18 db
18	Group	4 hours	4 hours	70 cps	60 cycles	18 db

V. SUMMARY

The two main types of "angel" interference noted at the Fort Dawes site during 1961-1962 were those that have been termed "single type" and "group" angels. Both types have been noted to occur under weather conditions which produce high temperatures, haze, and little or no winds. The majority of single type "angels" were found to have apparent doppler modulation frequency spectrums which peaked at or near 100 cycles per second. 3 db bandwidths was on the average 20 cycles per second or relatively narrow band. This angel type was always noted between 5 and 20 nautical miles in a 100° azimuth sector located east of the Deer Island radar site over water. The warm summer months provided the greatest amount of single type angel activity. Time duration for individual targets ranged from 15 seconds to 15 minutes. Activity usually started at midmorning with a few targets present and within two hours built up to enter sector coverage. Within two hours from the peak period only a few sporadic targets would remain. No apparent movement of these unknowns was noted from either "A" scope or PPI displays, rather they were observed to remain fixed geographically and to fade out at times and reappear in their original position sometime at a lesser intensity. Bi-Polar cancelled video "A" scope displays indicated the resemblance of single type angel returns to those of aircraft, however, they normally were at a smaller signal level.

Group angels were unknown targets that occurred in succession along an azimuth rector in the vicinity of 70°. Due to their intense signal level they give the appearance on PPI displays of being joined together either in portion or entirety. The range in nautical miles where this activity could be noted was at 7-20 miles and on occasions from 40-50 miles. The geographic location of these targets placed them over salt water. This variety of unknown activity usually occurred at midmorning or early afternoon and lasted for a time duration of 4 to 8 hours. "A" scope displays revealed a noise like, spikey nature to the video return. High speed 35 mm film analysis, however, produced a closely grouped array of targets which were coherent to one another but yet contained random doppler modulation. Apparent doppler modulation frequency bandwidth resulting from boxcar analysis was 40 to 400 cycles per second.

VI. CONCLUSIONS

Due to the electrical differences between single and group angel types previously explained it appears unlikely that a complete system cure for one would suffice for the other.

Single angel types could be eliminated by means of a filtering technique as shown in Figure 16. This system consists of shifting the zero points in the MTI comb filter response to the single type angel doppler modulation frequency. This is accomplished by generation of a new coho signal which is displaced by the "angel" doppler modulation frequency. After generation it is channeled into the radar system phase detector where it now represents a new coho signal and the comb filter response in which the null or 0 point shifts to the undesired angel doppler modulation frequency. The adjustable coho frequency will be gated on to cover the range extent occupied by the unwanted returns by means of the gate generator and switching arrangement shown in Figure 16.

Group angel elimination could be accomplished by the system shown in Figure 17. This is a form of non-coherent MTI circuitry where a small part of the undesired target (2 μ sec sample) will be phase compared with an adjacent 2 μ sec portion by means of a delay line technique. Range gating will again be applied so that the circuit can be used in areas where group angel activity exist. Residue remaining after cancellation will be reduced by using FTC circuitry.

Weather interference and warm-cold air mass frontal activity discussed in this report would perhaps be partially eliminated by the fix suggested for application to the single type angel activity. The most complete solution for elimination of weather activity since it contains random doppler modulation would be to add a circular polarization mode at the antenna system.

Future effort on the angel interference program will be to design and develop the circuitry "fixes" previously described and to apply these to the Fort Dawes FPS-8 radar system during the summer of 1963. The detailed results from this program will appear in the final engineering report.

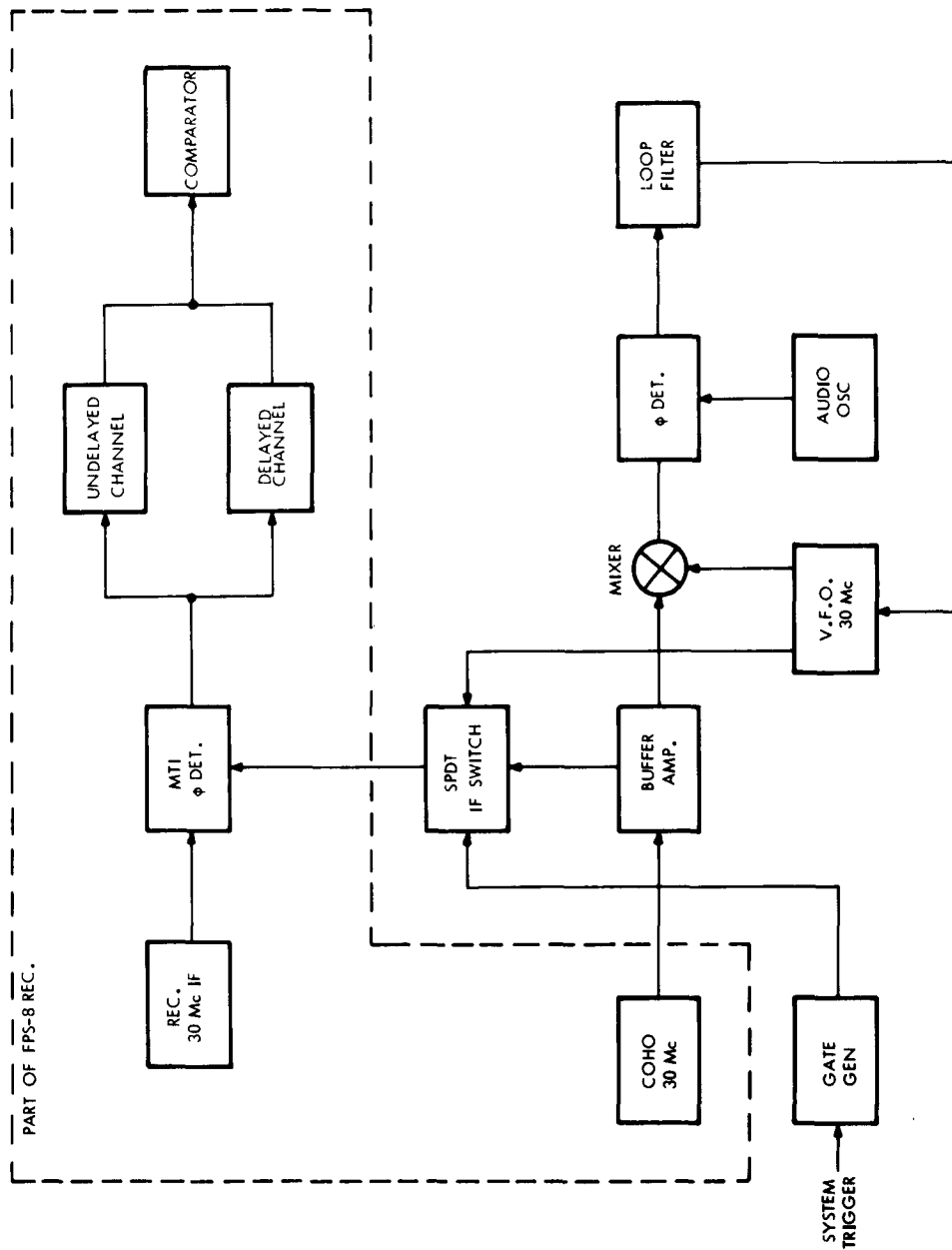


Figure 16. Adjustable Offset Coho

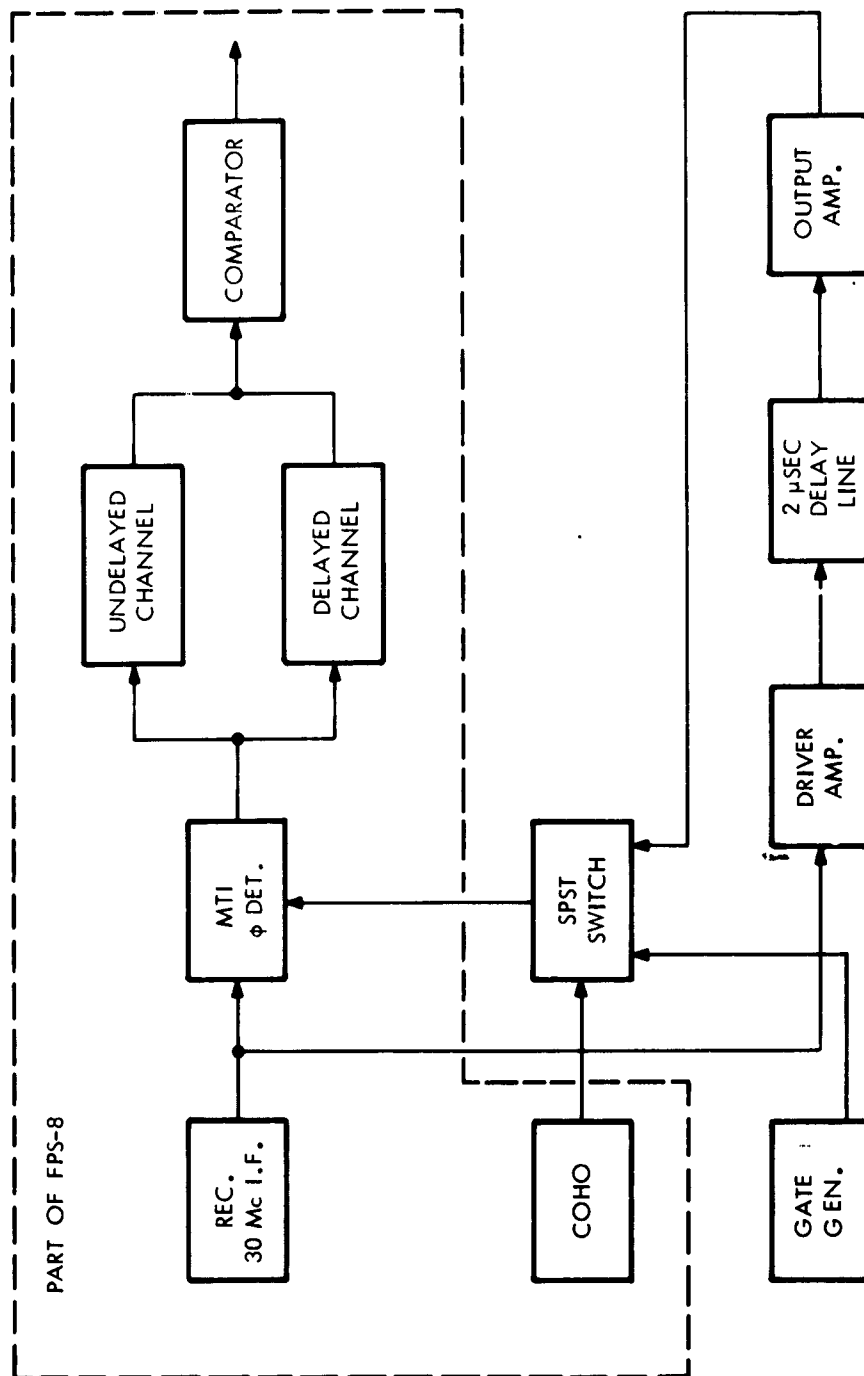


Figure 17. Modified Non-Coherent MTI

VII. APPENDIX

Previous Studies An Angel Activity

The Airborne Instruments Laboratory conducted a study¹³ during 1956 on Unidentified Targets (Angels) for Rome Air Development Center. Measurements were made to establish electrical characteristics of the angel return using AN/FPS-8, and AN/CPS-1 radars. Goals of the program were to determine any correlation between "angels" and wind velocity. Also to determine the doppler frequency spectrum of the angel interference.

Lincoln Laboratory²¹ studied "Angel" type return during 1959 at an L band radar site on Cape Cod. As a result of their measurements and calculations it was concluded that most of the overwater targets of unknown character observed at coastal sites were due to radar returns from birds. This bird problem it was believed was one of a distribution of individual targets having discrete velocities.

The Geophysics Research Directorate Air Force Cambridge Research Center published in 1956 a report titled "A Meteorological Study of Radar Angels"^{13, 14} which is based on radar studies of various types of "angel" return gathered over a fifteen month period using a K band system.

Numerous recordings of angel activity have been made on various radar systems over the years since as early as 1943¹⁻⁹. In general the only recorded data on these observations consisted of Plan Position Indicator Display photographs. These photographs gave shapes, grouping and some apparent velocity information. The bibliography at the end of this report gives a list of documents which made note of "angel" or other unknown phenomena.

Airborne Instruments Laboratory Study

During 1956 AIL conducted "angel" studies using an AN/FPS-9 L band radar at Mitchell Air Force Base, Long Island, New York¹³. Measurements were made over a period of several months, consisting of doppler frequency, doppler bandwidth, velocity, spectrum shape, and PPI grouping.

The method used by AIL for doppler spectral measurements was to "boxcar" (demodulate) the coherent video from the selected "angel" and to record the output of the demodulator on a tape recorder, splice a sample of this record into a loop, and to analyze the loop with a wave analyzer.

A Fairchild oscilloreord camera was used for pulse to pulse photographs of Angel Return on both coherent and normal video "A" scope presentations. With the scope intensity at maximum and a film (35 mm) speed of 1800 inches per minute sweep by sweep photographs were made of coherent video displays.

The results of the AIL study yielded the following information regarding "angel" electrical characteristics:

1. No absolute correlation appeared possible between wind conditions and the direction and velocity of "angel" returns.
2. "Angel" velocities are usually less than 50 knots.
3. The doppler frequency bandwidth of "angel" return ranges from 4 to 30 cps.
4. A reasonable percentage of "angel" return has a bandwidth of 10 cps or less.
5. The frequency of occurrence and the number of "angels" observed is proportional to the range capability of the radar system; therefore the "angel" problem will be more severe as more powerful radar system are utilized.

Lincoln Laboratory Study

During 1959 "Angel" observation studies were made by Lincoln Laboratory personnel on an L band radar at an Air Force Radar site on Cape Cod. 21 measurements of apparent doppler frequency and simultaneous rough measurements of range rate on an "A" scope were used in resolving velocity ambiguities of the "unknown" or, "angel" type MTI video return. By this means it was established that the range rate did not exceed 90 knots and that it was usually less than 50 or 60 knots. This "angel" velocity was also verified by scan by scan PPI 35 mm movie photography. Observations at various azimuths indicated that most of the targets were of the same type and were observed to remain in the beam of the searchlighting antenna for as little as a few seconds and sometimes for as long as several minutes. The scan-by-scan movies showed that many of the individual targets are discernible for an hour or more although usually they remained in a searchlighting beam for only a fraction of that time. Based on the information gathered and calculations, the conclusion was that most of the over-water targets observed at coastal sites were due to returns from birds and that the bird problem was one of a distribution of individual targets possessing discrete velocities.

Geophysics Research Directorate Study

"Angel" studies using a GRD "K" band radar (1.25 cm) were made during 1951-1953.^{10, 14} Although the study was 15 months in length only approximately 2.8 months of actual data was accrued due to poor facsimile records or because the records were completely obscured by precipitation echoes. A Fairchild camera fitted to an A/R scope was used to record "angel" intensities vs. range over a given time period with the antenna held stationary. These measurements were made using a vertical mounted and a horizontal mounted antenna. Both antenna systems were fixed in a given azimuth or elevation and "angel" targets recorded as they passed through the radar beam.

As a result of accrued data the following conclusions were felt valid:

1. Horizontal size of certain "angel" sources are indicated to range up to 70 feet.
2. The vertical angel dimensions or thickness were 0 - 180 ft. for weak echoes and 180 - 360 ft. for strong echoes.
3. "Angel" persistence was found to be 0.2 - 0.3 second.
4. Low wind velocity and high temperatures were found to be associated with periods of high "angel" activity.

VIII. BIBLIOGRAPHY ON RADAR ANGEL RETURN

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<p>HQ ESD, L. G. HANSCOM FIELD, BEDFORD, MASS. ESD TDR 63-221, RADAR INTERFERENCE STUDY INTERIM REPORT., 27 January 1963, 50P INCL</p> <p>THIS REPORT DESCRIBES THE METHODS USED TO RECORD AND ANALYZE VIDEO RETURN FROM "ANGEL" TYPE RADAR INTERFERENCE. RESULTS OF THE ANALYZED DATA ARE DISCUSSED IN DETAIL AND ALSO THE CONDITIONS UNDER WHICH THE SIGNALS WERE OBSERVED. TWO POSSIBLE CIRCUITS FOR ELIMINATING THE INTERFERENCE IN THE RADAR MTI SYSTEM ARE DISCUSSED.</p>	<ol style="list-style-type: none"> 1. INTERFERENCE DATA STORAGE. 2. INTERFERENCE DATA REDUCTION. 3. MTI CIRCUIT MODIFICATIONS. <ol style="list-style-type: none"> I. CONTRACT AF19(604) 8484. II. SYLVANIA WALTHAM LABS. WALTHAM, MASS. III. W. B. MILLS IV. IN ASTIA COLLECTION.
<p>HQ ESD, L. G. HANSCOM FIELD, BEDFORD, MASS. ESD TDR 63-221, RADAR INTERFERENCE STUDY INTERIM REPORT., 27 January 1963, 50P INCL</p> <p>THIS REPORT DESCRIBES THE METHODS USED TO RECORD AND ANALYZE VIDEO RETURN FROM "ANGEL" TYPE RADAR INTERFERENCE. RESULTS OF THE ANALYZED DATA ARE DISCUSSED IN DETAIL AND ALSO THE CONDITIONS UNDER WHICH THE SIGNALS WERE OBSERVED. TWO POSSIBLE CIRCUITS FOR ELIMINATING THE INTERFERENCE IN THE RADAR MTI SYSTEM ARE DISCUSSED.</p>	<ol style="list-style-type: none"> 1. INTERFERENCE DATA STORAGE. 2. INTERFERENCE DATA REDUCTION. 3. MTI CIRCUIT MODIFICATIONS. <ol style="list-style-type: none"> I. CONTRACT AF19(604) 8484. II. SYLVANIA WALTHAM LABS. WALTHAM, MASS. III. W. B. MILLS IV. IN ASTIA COLLECTION.
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